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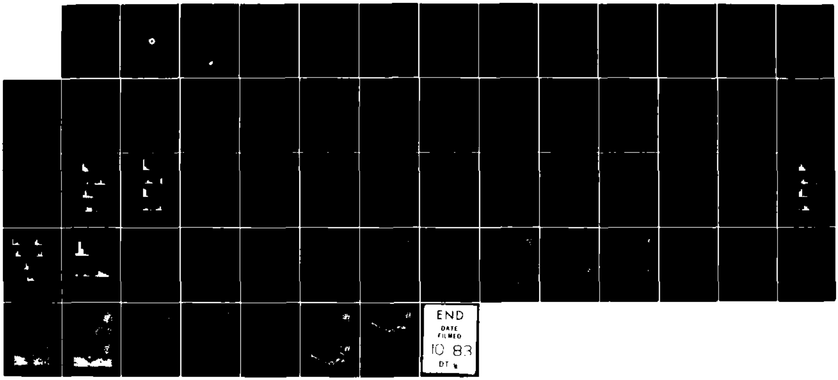

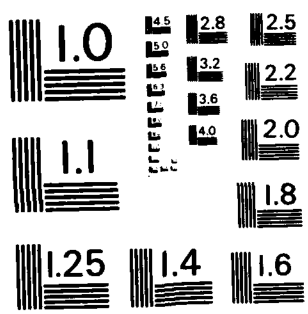

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MOVEMENT OF SATELLITE-TRACKED BUOYS IN THE BEAUFORT SEA (1979-1981)

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AD-A133 259

Interim Report

June 1983

PREPARED FOR
U. S. DEPARTMENT OF TRANSPORTATION
UNITED STATES COAST GUARD

OFFICE OF RESEARCH AND DEVELOPMENT
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NOTICE

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16. Abstract

As part of an investigation into the fate of potential Arctic oil spills, the U.S. Coast Guard Research and Development Center and Canadian Marine Drilling Ltd (CANMAR) released satellite-tracked platforms at the Canadian offshore drilling sites in the southeastern Beaufort Sea. During the first three years of joint research effort, which began in 1979, 21 trajectories were compiled, 15 from oceanographic drifters released in summer open water conditions and 6 from platforms deployed onto Arctic Ocean sea ice.

The movement of the 15 oceanographic drifters showed considerable interannual variability. In 1979 the buoys moved offshore and to the west, paralleling the Alaskan coast, a direction which is consistent to the east-to-west motion of the southern portion of the Beaufort Sea Gyre. The 1980 and 1981 drift data show no such consistent behavior. In 1980 the buoys first moved to the east; three of the buoys then reversed directions and moved to the west in response to persistent winds from the east and northeast. The 1981 data exhibited the most dramatic easterly movement with five buoys grounding on or near the Tuktoyaktuk Peninsula, a short distance from the release site.

Despite this remarkable yearly variability, at least one buoy drifted into U.S. waters in each of the first three years of the study. This, in addition to the fact that the ice movement data show a net westward motion, suggests that the Alaskan coast could be affected by a major uncontained blowout during Canadian offshore operations.

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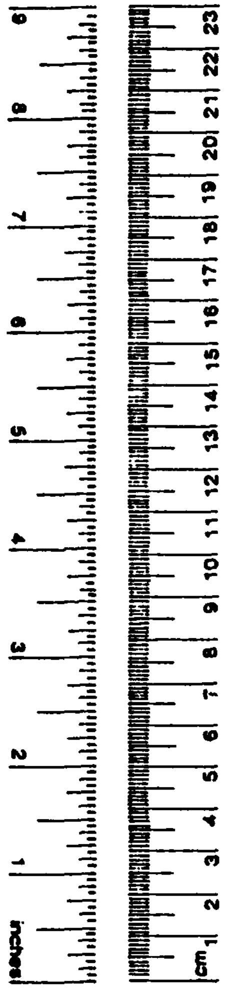
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

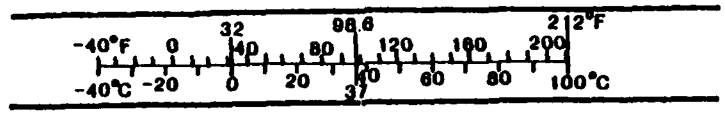
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures. Price $2.25. SD Catalog No. C13.10.286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1.0 INTRODUCTION

As part of its investigation into the fate of potential Arctic oil spills, the U.S. Coast Guard Research and Development Center (R&DC) in 1979 began a series of drift studies in the Beaufort Sea (Figure 1-1) using satellite-tracked platforms.

This research effort is motivated by the development of Beaufort Sea oil resources in both Canadian and United States waters, and the recognition that there is a concomittant possibility for an accidental marine oil spill in the region. Even with the most sophisticated containment and recovery techniques, it is not likely that 100% of the spilled oil can be contained at an Arctic spill site. This task is difficult enough in temperate waters; in the Arctic the problem is complicated significantly by the presence of sea ice during most of the year. The result could be an oil slick moving in the complex Arctic environment, which requires that an oil spill model be employed to predict spill movement.

The primary goal of this research is to examine the surface flow field in the Beaufort Sea, particularly the interannual variability and the range of motions one would likely encounter during an Arctic oil spill. It has long been recognized that the accuracy of the most sophisticated of mathematical oil spill models rests on the quality of the available surface current data. The Beaufort Sea is a data sparse area, and until recently little attention has been given to the oceanography of the region.

Since its inception, this research program has been a cooperative effort between R&DC and Canadian Marine Drilling, Ltd. (CANMAR), a subsidiary of Dome Petroleum, a major Canadian oil company. Thus far, the study has focused on the movement of satellite-tracked platforms, both freely-drifting buoys and ice buoys, deployed at the CANMAR offshore drilling sites north of the Tuktoyaktuk Peninsula, Northwest Territories. The deployment site is located in a region of confirmed oil resources and where exploration continues; production in this area could commence as early as the late 1980's.

This report is the second in a series of reports documenting the results of the R&DC Beaufort Sea drift program. The first (Murphy et al. 1981) described the 1979 deployments in detail. The present report describes the data from the first three years of the program (1979 through 1981); it treats the 1979 data in general terms and presents in detail the results of the 1980 and 1981 platform deployments. In 1981 four satellite-tracked platforms were deployed onto Arctic Ocean sea ice as part of two independent U.S. Coast Guard projects, three as part of the R&DC Ice Research program and one in support of the USCGC POLAR SEA winter 1981 Arctic deployment (Shuhy, 1981). Those data are also presented in the present report.

It is not the intent of this report to present an exhaustive analysis of the platform motions, but rather to describe the data in the framework of the large scale atmospheric systems and ice cover environment.

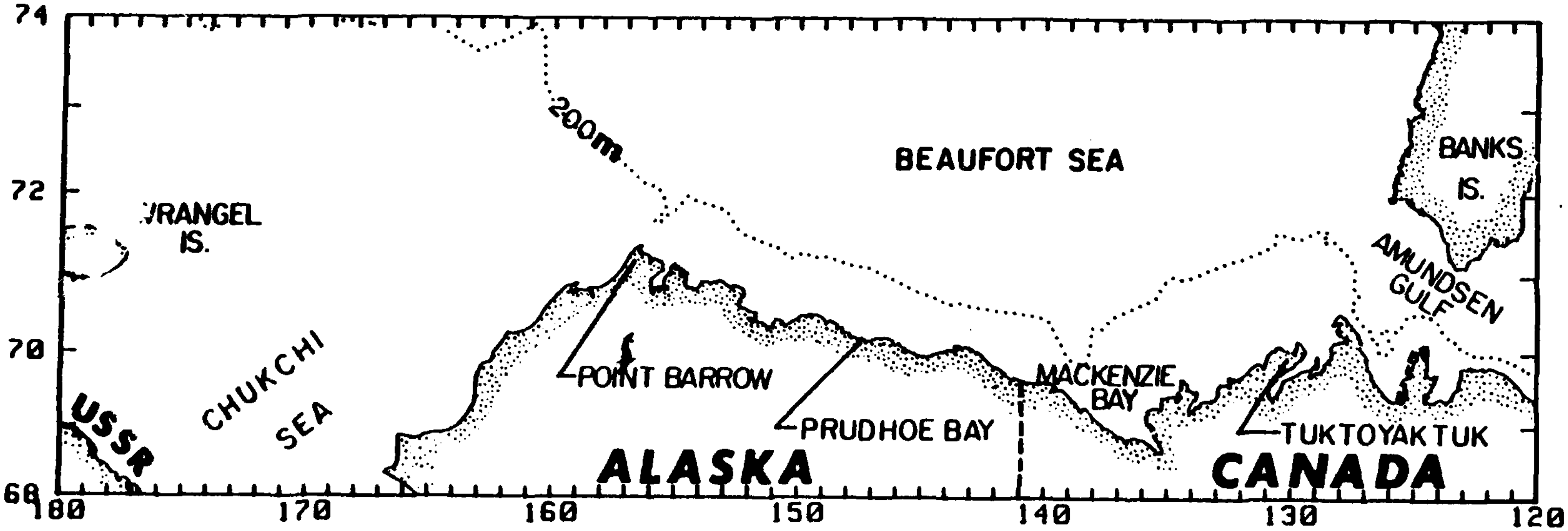

FIGURE 1-1. Area of Study.

Throughout this report, Julian dates (JD) are presented where appropriate because this calendar system, in which the days of the year are numbered sequentially starting 1 January, is convenient when dealing with drift intervals spanning several months.

2.0 MEASUREMENT PROGRAM

2.1 Tracking System and Platform Description

Two different satellite tracking systems and several different platform designs were employed in this study. The first tracking system, used only in 1979, was the Random Access Measurement System (RAMS) on board the NIMBUS 6 satellite; Kirwan et al. (1976) provide a summary of RAMS. The advertised position accuracy of RAMS is $\pm$ 5 km. The second tracking system, used after 1979, was the ARGOS system on board the TIROS/NOAA series satellites. It provides a system position accuracy of approximately 300 meters; Bessis (1981) describes the ARGOS system. For both the RAMS and ARGOS systems, the buoy positions are determined by a Doppler shift in the carrier frequency of the buoy transmissions during a satellite pass.

Two fundamentally different platform types were used in this study; their movement is used to address two vastly different Arctic oil spill scenerios. The first platform was a freely floating drift-buoy, also called an oceanographic drifter, which follows surface currents. This platform type was used to investigate the surface currents as they relate to the oil movement from a spill occurring in the ice-free or open water conditions of the Arctic summer. The second platform type was an Arctic drifter which was deployed onto, and tracks the movement of, sea ice. Its movement is used to simulate the motion of oil entrapped in sea ice, a likely occurrence should oil be spilled under an ice cover.

Three different oceanographic drifter hulls were used. The first type, used in 1979, was designed and constructed at Scripps Institute of Oceanography (SIO) and will be referred to as the SIO hull. It consisted of a fiberglass cylinder approximately 3 meters long (Figure 2-1). The remaining two hull types were designed and manufactured at Polar Research Laboratory (PRL) of Santa Barbara, California. The first was the standard PRL hull (Figure 2-2) which is approximately the same length as the SIO hull. The PRL hulls used in 1980 were fitted with 2x11 m nylon window shade drogues tethered to the buoy with 30 m of nylon line. A drogue sensor which incorporated a load cell was mounted on the lower end of the buoy hull. This sensor provided a drogue "on/off" indicator along with the position data. This hull type will be referred to as the PRL hull. The third hull type (Figure 2-3) used in this study was designed by PRL especially for CANMAR. It is 1.12 m in diameter with a 0.20 m drag skirt. The buoy floats nearly awash, with only a 0.38 m antenna above the water surface. It will be referred to as the CANMAR hull.

The TIROS Arctic Drifter (TAD), manufactured by PRL, was used to track the movement of sea ice. The particular version used (Figure 2-4) was air-deployable, although in most cases it was convenient to land the aircraft and hand-deploy the platform.

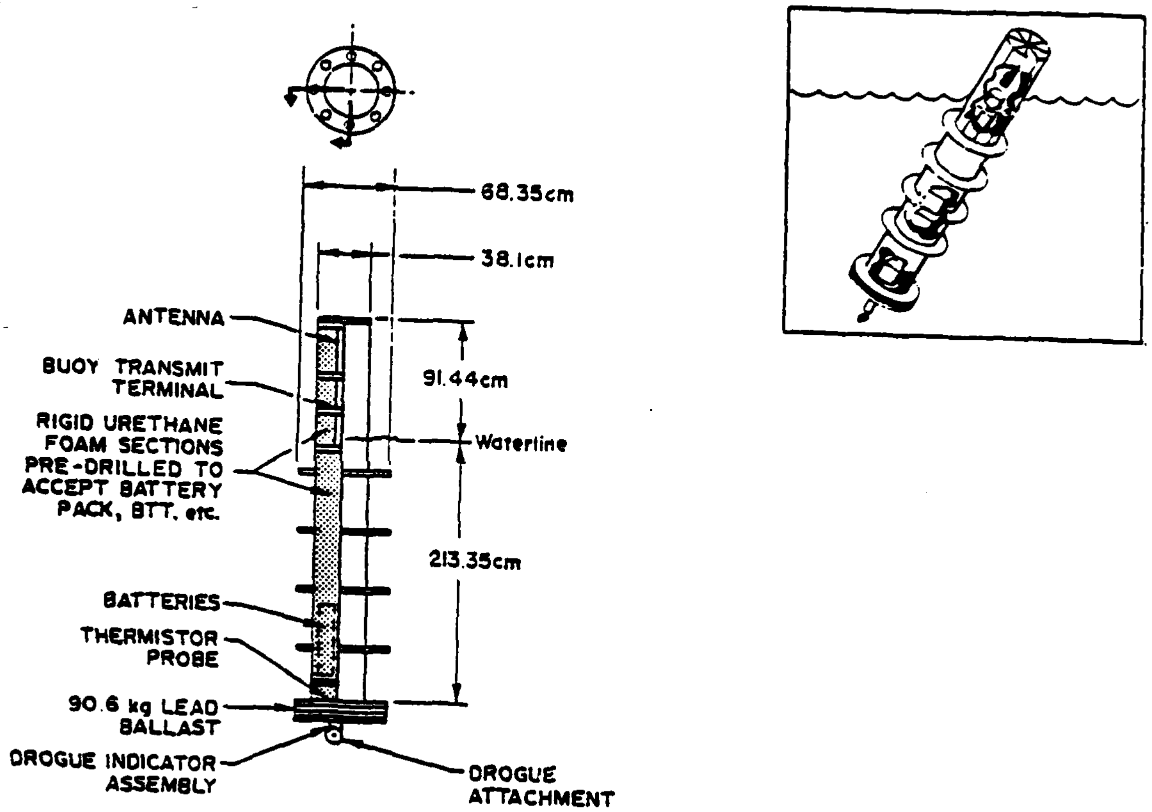

FIGURE 2-1. Scripps Institute of Oceanography (SIO) Hull Design.

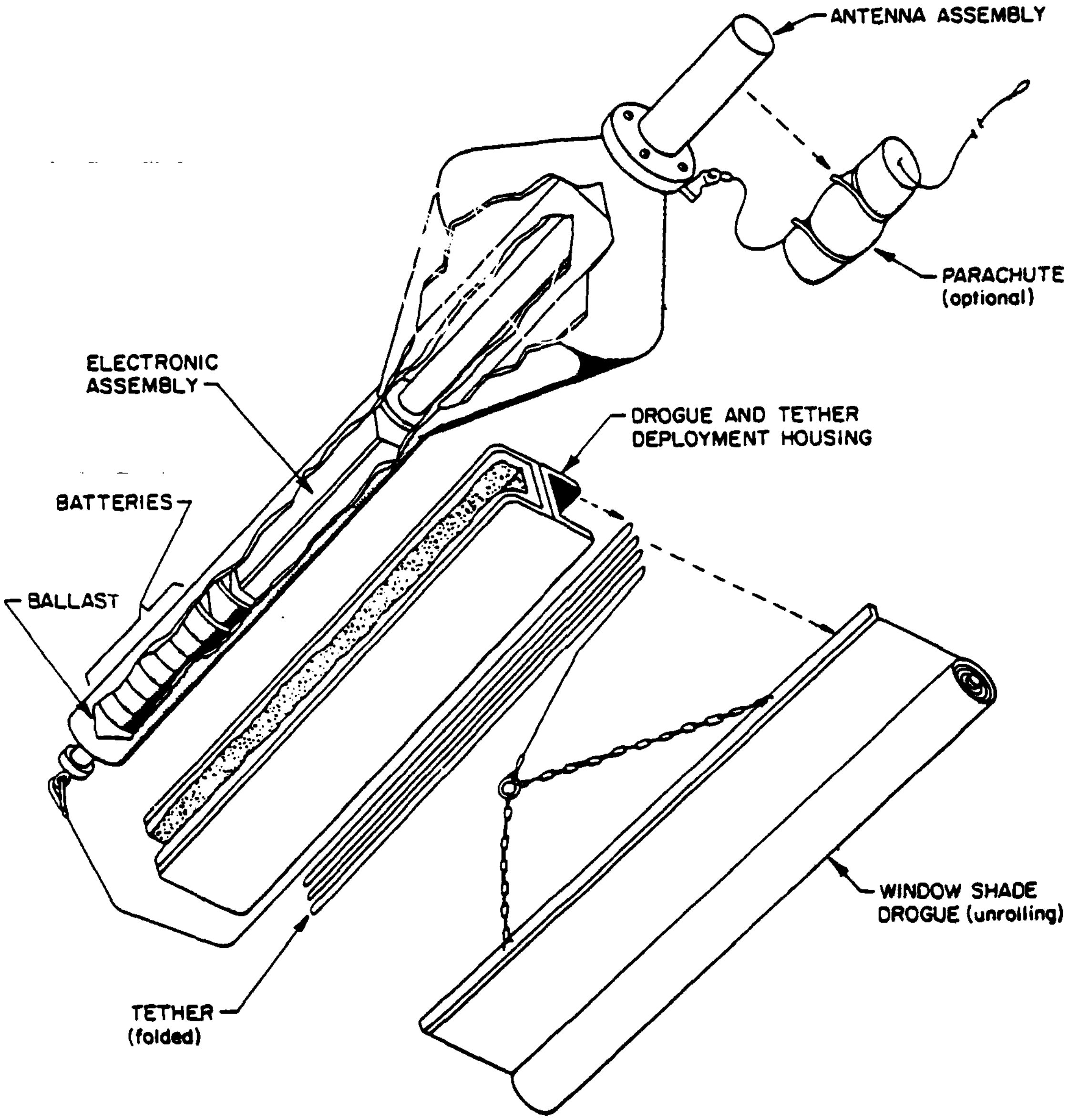

FIGURE 2-2. Polar Research Laboratory (PRL) Hull Design.

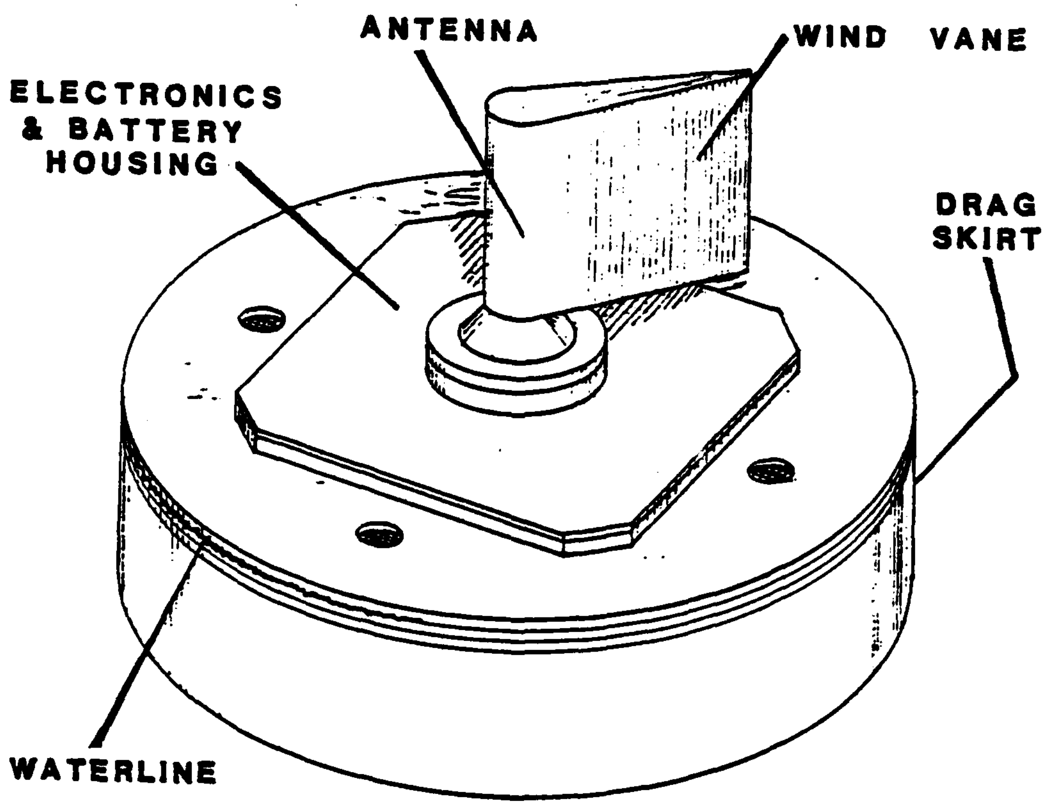

FIGURE 2-3. CANMAR Hull Design.

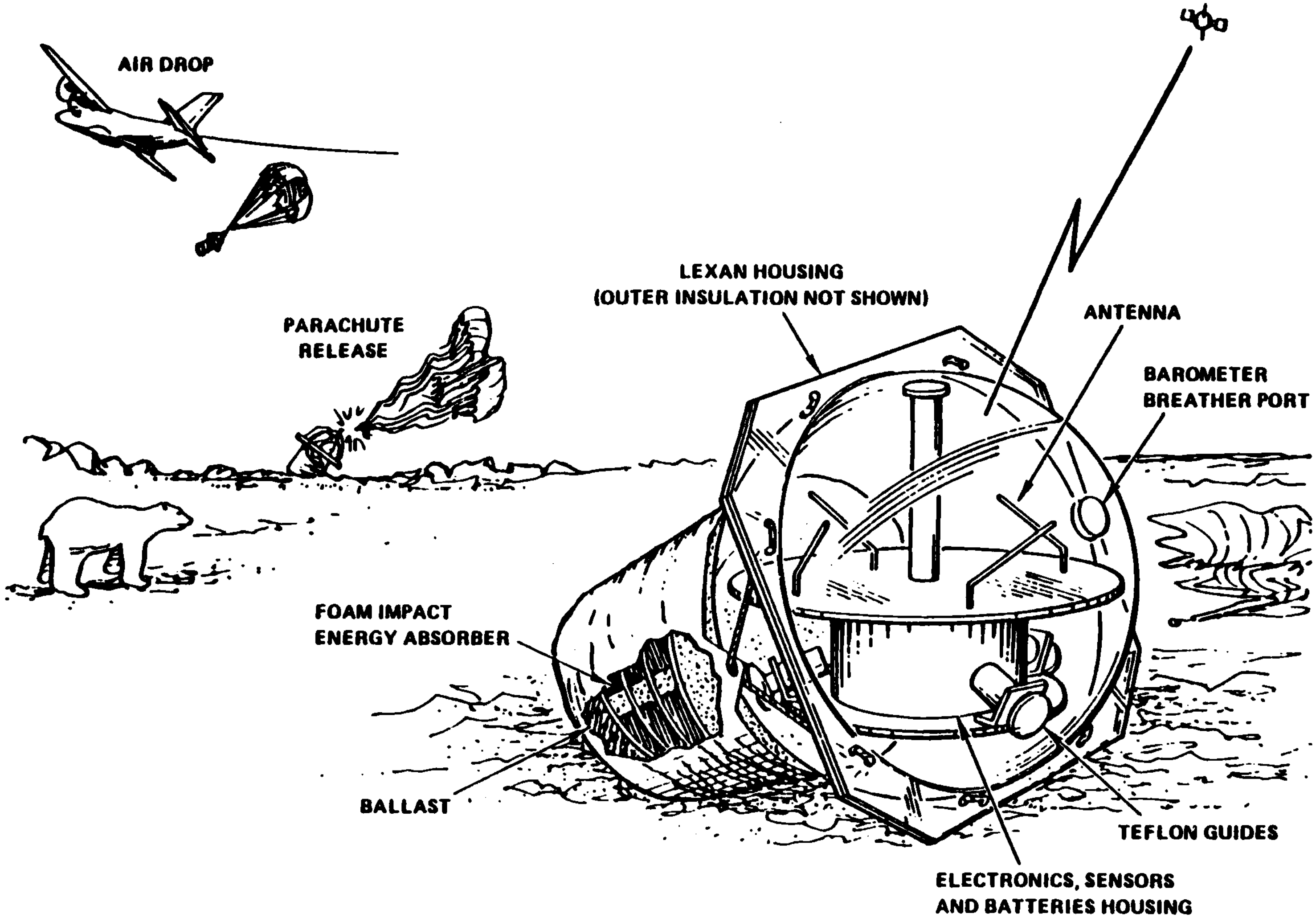

FIGURE 2-4. TIROS Arctic Drifter (TAD), Air-Deployable.

Little needs to be said about what the motion of a TAD represents. The TAD track is that of the ice floe upon which it was placed, and the only uncertainty lies in what happens to it when it enters the water, for example, falls into a lead. It is likely that the TAD stops transmitting, and experience with iceberg tracking supports this contention (R.Q. Robe, personal communication).

The matter of what the motion of the oceanographic drifters represents is the subject of more uncertainty. Even for the drogued PRL buoys it is probably best to assume that all the oceanographic drifters followed the currents in the upper (1 to 2 meters) portion of the water column. The actual fate of the drogues is uncertain as is described later.

There is, of course, some downwind buoy movement due to the wind stress acting directly on the exposed (above the water line) portion of the hull. It is variously called leeway or slippage (with respect to the water), and it contaminates the surface current information that the buoy trajectory indicates.

For the SIO and PRL hulls the ratio of the submerged area to exposed area was at least 2:1; thus the wind stress on the buoy hull is not expected to dominate the buoy motions. Kirwan et al. (1978) attempted to correct the buoy movement records by eliminating direct wind effects, but they found unrealistically high corrections and concluded that the uncorrected records were better representations of the ocean surface currents. McNally (1981), using drifters with SIO hulls in the northern Pacific, showed that there was no significant systematic difference between the movement of undrogued drifters and those with drogues at 30 m, which suggests that the slippage of his buoys was small compared to the wind-driven currents.

The hull design of the CANMAR buoys is quite different from the relatively similar SIO and PRL hulls. The intent of CANMAR was to develop a buoy hull which would travel like an oil slick. The issue of how well the movement of the CANMAR hull fulfills this goal is not addressed in this report. The drift data are presented and, in particular, the movement of the CANMAR hull is compared to the PRL hulls for the cases in which the two types were released together.

2.2 Position Data Processing

For the 1979 deployment, the RAMS system provided an average of one good fix every 1.4 days. On some occasions there were four or five good positions per day, while at other times, there were data gaps of up to ten days. The sporadic nature of the data limited the sophistication of the data processing. As a result, a simple two-point linear interpolation scheme was used to generate an equally spaced record of positions with a time interval of 48 hours; no filtering was attempted.

The position data collected from the ARGOS system in 1980-1981 were less sporadic. There were very few data gaps and 10 or more good fixes were recorded each day for all of the platforms. The position data were processed in a manner following Robe and Maier (1979). Equally spaced position records with a three-hour time interval were computed using a four-point linear interpolation scheme. These position records were then filtered using a low-pass filter with a cut-off of 1.16×10^{-5} Hz (one cycle per day). This filter removes the random system errors and most of the tidal effects. The buoy drift speeds and directions were computed from the filtered files using a simple two-point backward differencing scheme.

2.3 Sea Ice Concentrations

Data concerning sea ice concentrations and distributions in the Beaufort Sea were obtained from atlases prepared by the Joint Ice Center (JIC) in Suitland, Maryland (NOAA/US Navy Joint Ice Center, 1979-1981). The terminology used in the text follows that employed by the JIC. The ice concentrations are presented in tenths. Open water refers to ice concentrations of $<1/10$, and ice-free indicates that there is no sea ice present. The ice is also classified by age; multi-year and second-year ice are indicated by OLD (2.0 to 3.5 m thick) while first-year ice (FY) includes all first-year ice types (0.30 m to 2 m thick). Young ice (10 to 30 cm) is denoted by YNG, and N refers to new and nilas (an elastic crust of ice <10 cm thick).

Sea ice concentrations data are presented for the appropriate periods in 1980 and 1981 in Appendices A and B respectively. The data for the 1979 oceanographic drifter deployment are presented in Murphy et al. (1981) and are not repeated here.

2.4 Wind Data

Direct wind measurements over water or ice in the Arctic Ocean are rare. As a result, surface wind data are computed from the distribution of surface atmospheric pressure using the geostrophic equations and applying a relationship between geostrophic wind and the actual surface wind. This method is described by Petterssen (1958).

The data used in this report were obtained from two sources. The first, used only in 1979, was the National Meteorological Center (NMC) 1000 mb velocity field, a wind field which is essentially geostrophic. The second source, used in 1980 and 1981, was the daily Arctic atmospheric pressure fields presented by Thorndike and Colony (1981) and Thorndike et al. (1982).

3.0 YEARLY PLATFORM TRAJECTORIES

In this section the trajectories of the platforms deployed from 1979 through 1981 are described. A total of twenty-one tracks, fifteen oceanographic buoys and six TAD's, are presented in chronological order based on the release date. Data summaries for each of the three years are presented in Tables 3-1 through 3-3.

3.1 Summer 1979

Seven freely-drifting buoys, all with SIO hulls and NIMBUS electronics, were deployed into ice-free waters at CANMAR drilling sites north of Richards Island (Figures 3-1a through 3-1e). They were released on two dates, three buoys on 9 August (JD 221) and four buoys on 30 August (JD 242), along a north-south line 50 km long starting approximately 50 km offshore; none of the buoys had drogues. The goal was to study both the spatial and temporal variability of the nearshore surface flow.

TABLE 3-1. 1979 DATA SUMMARY

ID #	HULL TYPE	TRACKING SYSTEM	RELEASE POSITION LATITUDE (DEG-MIN)	RELEASE POSITION LONGITUDE (DEG-MIN)	DROGUE	RELEASE DATE (JULIAN DAY)	DATE BUOY STOPPED TRANSMITTING OR GROUNDED
226	SIO	NIMBUS	70-16	133-22	NO	9 Aug 79 (221)	31 Dec 79 (365)
235	SIO	NIMBUS	70-03	133-22	NO	30 Aug 79 (242)	-
257	SIO	NIMBUS	70-09	133-24	NO	30 Aug 79 (242)	-
261	SIO	NIMBUS	70-20	133-27	NO	30 Aug 79 (242)	22 Oct 79 (295)
404	SIO	NIMBUS	70-31	133-28	NO	30 Aug 79 (242)	19 Oct 79 (292)
432	SIO	NIMBUS	70-27	133-24	NO	9 Aug 29 (221)	30 Nov 79 (334)
443	SIO	NIMBUS	70-05	133-20	NO	9 Aug 79 (221)	11 Feb 80 (42)

TABLE 3-2. 1980 DATA SUMMARY

ID #	HULL TYPE	TRACKING SYSTEM	RELEASE POSITION LATITUDE (DEG-MIN)	RELEASE POSITION LONGITUDE (DEG-MIN)	DROGUE	RELEASE DATE (JULIAN DAY)	DATA BUOY STOPPED TRANSMITTING OR GROUNDED
2581	PRL	TIROS	70-22	134-08	YES	17 Aug 80 (230)	7 Jan 81 (7)
2582[1]	PRL	TIROS	70-22	134-08	YES	21 Aug 80 (234)	11 May 81 (131)
2583[1]	PRL	TIROS	70-22	134-08	YES	21 Aug 80 (234)	29 Sep 80 (273)
2584	PRL	TIROS	70-22	134-08	YES	13 Aug 80 (226)	13 Aug 80 (228)
2585	TAD	TIROS	70-12	133-29	-	8 Dec 80 (343)	17 Dec 80 (352)
2586	TAD	TIROS	70-13	133-20	-	8 Dec 80 (343)	9 Jul 81 (190)
2587[1]	CANMAR	TIROS	70-22	134-08	NO	21 Aug 80 (234)	21 Feb 81 (52)
2588	CANMAR	TIROS	70-22	134-08	NO	29 Aug 80 (242)	1 Sep 80 (245)
2589	CANMAR	TIROS	70-22	134-08	NO	25 Sep 80 (238)	17 Sep 80 (261)
2590	CANMAR	TIROS	70-22	134-08	NO	2 Sep 80 (246)	-

Notes: 1. Buoys 2582, 2583, and 2587 were deployed together.

TABLE 3-3. 1981 DATA SUMMARY

ID #	HULL TYPE	TRACKING SYSTEM	RELEASE POSITION LATITUDE (DEG-MIN)	RELEASE POSITION LONGITUDE (DEG-MIN)	DROGUE	RELEASE DATE (JULIAN DAY)	DATA BUOY STOPPED TRANSMITTING OR GROUNDED
2600	PRL	TIROS	70-22	134-08	NO	15 Aug 81 (227)	30 Aug 81 (242)
2601	PRL	TIROS	70-22	134-08	NO	22 Aug 81 (234)	2 Sep 81 (245)
2602	PRL	TIROS	70-22	134-08	NO	15 Aug 81 (227)	FAILED
2603	PRL	TIROS	70-22	134-08	NO	5 Sep 81 (248)	UNAUTHORIZED RETRIEVAL
2604	CANMAR	TIROS	70-22	134-08	NO	4 Sep 81 (247)	4 Nov 81 (308)
2606	CANMAR	TIROS	70-22	134-08	NO	22 Aug 81 (234)	1 Sep 81 (244)
2607	CANMAR	TIROS	70-22	134-08	NO	15 Aug 81 (227)	3 Sep 81 (246)
2608	CANMAR	TIROS	70-22	134-08	NO	18 Aug 81 (230)	4 Sep 81 (247)
2619	TAD/AD[1]	TIROS	71-34	173-08	-	3 Apr 81 (93)	6 Jan 82 (6)
2577	TAD/AD	TIROS	71-34	148-20	-	6 Apr 81 (96)	7 Oct 81 (280)
2578	TAD/AD	TIROS	72-19	133-54	-	16 Apr 81 (106)	8 Jul 81 (189)
2579	TAD/AD	TIROS	75-07	138-04	-	11 Apr 81 (101)	25 Aug 81 (237)

Note 1: TIROS Arctic Drifter (Air Deployable)

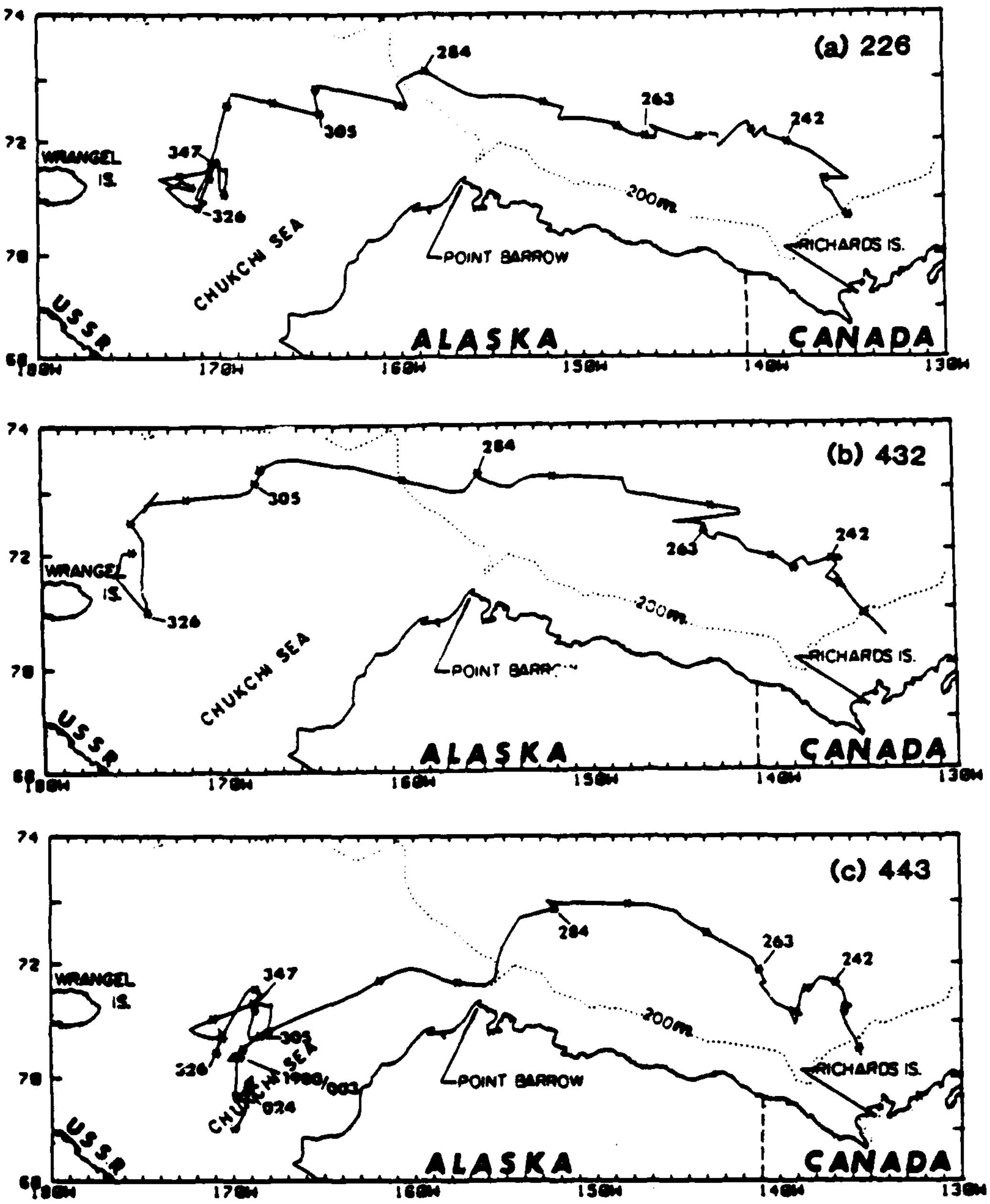

FIGURE 3-1. Trajectories for Buoys Released in 1979: (a) Buoy 226, (b) Buoy 432, (c) Buoy 443, all released 9 August (JD 221); and (d) Buoy 261, and (e) Buoy 404 both released 30 August (JD 242). The dates are given in Julian Days; asterisks are plotted at seven day intervals. Continued on next page.

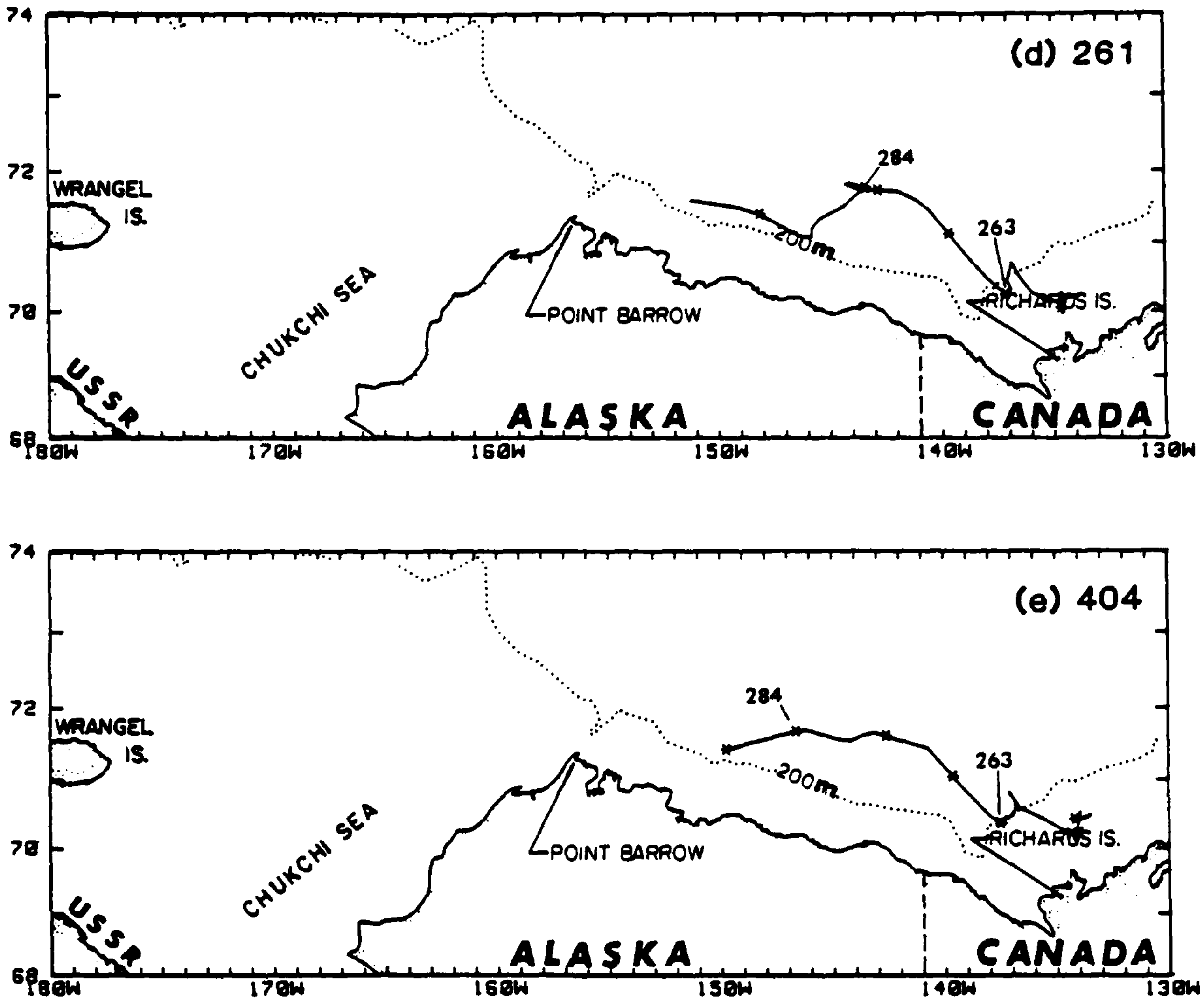

FIGURE 3-1 (Cont'd) Trajectories for Buoys Released in 1979: (a) Buoy 226, (b) Buoy 432, (c) Buoy 443, all released 9 August (JD 221); and (d) Buoy 261, and (e) Buoy 404 both released 30 August (JD 242). Dates are given in Julian Days; asterisks are plotted at seven-day intervals.

Of the seven buoys, one stopped transmitting immediately after its release and another grounded on Richards Island a short distance from the release site. The remaining five buoys traversed the Beaufort Sea in an east-to-west direction.

The three buoys released on 9 August (JD 221) moved rapidly to the northwest out of the deployment area (Figure 3-1a through 3-1c) under moderate to strong southeast and south winds in mid-August. They continued to move predominantly from east to west across the Beaufort Sea, parallel to the Alaskan coast and approximately 200 km offshore. This movement occurred in ice-free and open water considerably off the continental shelf. They returned to the continental shelf near Pt. Barrow in mid-October, approximately two months after their release. To the west of Pt. Barrow, they turned somewhat to the south and entered the Chukchi Sea where they encountered 7/10 to 10/10 N/YNG sea ice in mid-November. By 11 February 1980 (JD 42), all three of these buoys had ceased transmitting.

The two remaining buoys from the 30 August (JD 242) deployment also moved quickly out of the release area to the northwest, and thence to the west along the Alaskan coast (Figure 3-1d and 3-1e). They moved somewhat inshore of the three released earlier, but off the continental shelf as well. Their early movements were in ice-free waters, but by mid-October they encountered 7/10 to 10/10 N/YNG sea ice east of Pt. Barrow and stopped transmitting positions shortly thereafter.

Murphy et al. (1981) compared weekly averaged buoy motions with similarly averaged surface winds calculated from the NMC 1000 mb atmospheric velocity field. For the period that the buoys moved in either ice-free or open water, they computed the buoy speed as a percentage of the surface wind speed and the deflection angle (the angle that the buoy moves relative to the wind direction). They found considerable scatter in the data at low wind speeds; however, for surface wind speeds greater than 5 ms^{-1} the buoys were found to move consistently at 3.8% and 22° to the right of the local wind.

3.2 Summer 1980

During the summer of 1980 eight oceanographic drift-buoys, tracked using the ARGOS System, were released into ice-free waters at four-day intervals over the period from 13 August (JD 226) through 2 September (JD 246); the launch site is denoted by an "X" in Figures 3-2a and 3-2b. Two hull types were used: four PRL hulls with window shade drogues tethered at 30 meters and four undrogued CANMAR hulls. The primary goal of the 1980 open water effort in 1980 was to examine the temporal variability of the surface flow in the study area.

Of the eight buoys released, one failed immediately due to an apparent electronic malfunction, and two others provided positions for only a few days. At least one of these was reportedly hit by an ice-breaking vessel operating in the study area. The tracks of four of the five remaining buoys are shown in Figures 3-2a and 3-2b; the fate of the fifth buoy is discussed later.

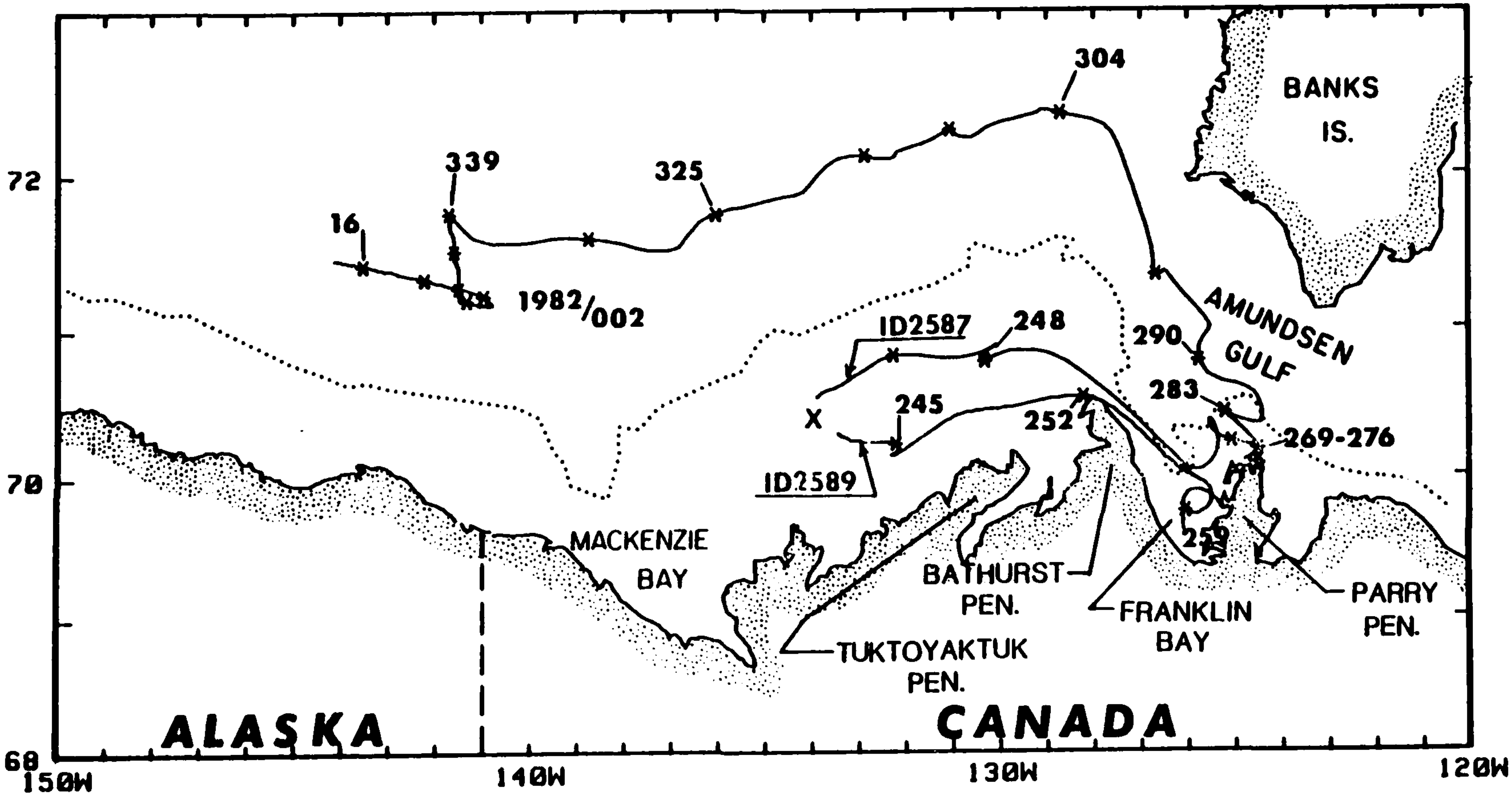

FIGURE 3-2a. Filtered Trajectories for Buoy 2587 Released 21 August (JD 234) 1980 and Buoy 2589 Released 25 August (JD 238) 1980. The approximate location of the release site is marked by an "X". The dates are given in Julian Days; asterisks are plotted at seven-day intervals.

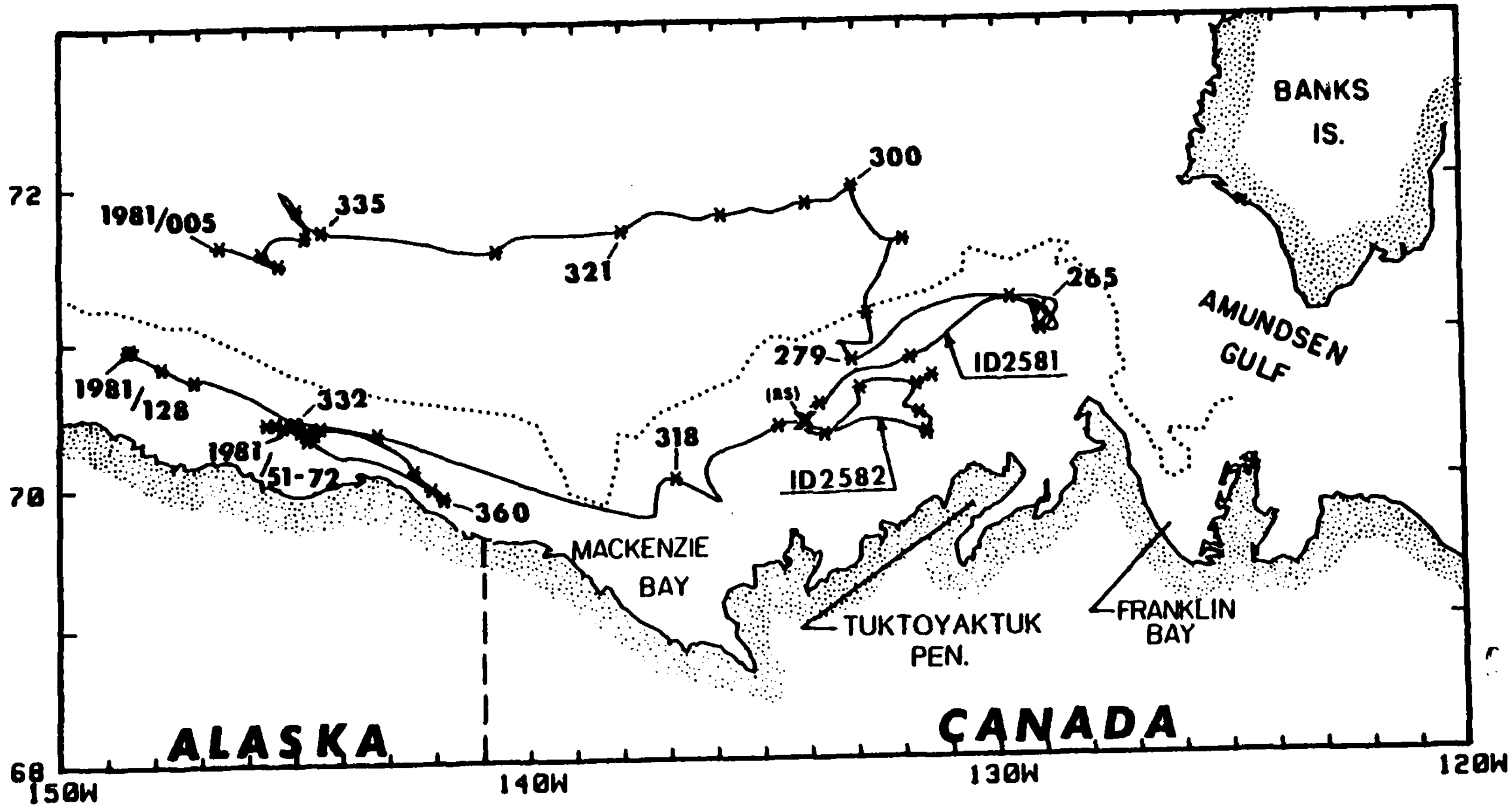

FIGURE 3-2b. Filtered Trajectories for Buoy 2581 Released 17 August (JD 230) 1980 and Buoy 2582 Released 21 August (JD 234) 1980. The approximate location of the release site is marked by an "X". The dates are given in Julian Days; asterisks are plotted at seven-day intervals.

The 1980 tracks are considerably different from those in 1979, particularly the easterly motion which occurred in the first few weeks after the releases. During this period (mid-August to mid-September), the atmospheric circulation in the Arctic Ocean was dominated by a low pressure system which resulted in west and northwest winds in the study area. The response of two of the buoys (2587 and 2589), both with CANMAR hulls, was quite dramatic (Figure 3-2a). They moved persistently to the east entering Amundsen Gulf and then Franklin Bay. Twelve-hour average speeds of up to 0.59 ms^{-1} were measured in the area north of Bathurst Peninsula. Both buoys beached on the Parry Peninsula, one permanently (2589 on 17 September, JD 261) and the other (2587) for two weeks (21 September, JD 265, to 5 October, JD 279), a period during which there was a considerable amount (8/10 to 10/10) of FY/OLD sea ice in the vicinity.

Unfortunately, the early position data from the drogue-equipped PRL hulls must be viewed with skepticism. The drogue tethers (30 m) were too long for the shallow water which they entered under the forcing of the northwest winds. Often, these buoys were near or within the 50-meter bathymetric contour; therefore, it is likely that the drogue was in contact with the bottom for extended periods. Adding to the uncertainty is the fact that the actual fate of the drogues is unknown, because in all cases, the drogue "on/off" indicator showed that the drogues had detached shortly ($<$10 days) after deployment.

The drogue problem explains the lack of significant eastward movement of the drogued buoys during the persistent northwest winds. In fact, one of the buoys (2583) was clearly in water too shallow for the drogue and never returned to deep water. Its track is of little value and is not plotted in Figure 3-2b. The remaining two drogued buoys (2581 and 2582) were eventually blown clear of the shallow water; however, because of the recognized reliability problems of the "on/off" indicator, the fate of the drogue is uncertain. It is assumed that the drogues detached.

During early October there were several periods of strong south to southeast winds; this explains the persistent northward tracks of 2587 and 2581 (5 October, JD 279, to 28 October, JD 302). Both buoys were in heavy sea ice concentrations (9/10 to 10/10) although 2587 was in an area of N/YNG ice, while buoy 2581 was near areas of thicker OLD ice.

A period of remarkably coherent westward movement is apparent in the trajectories of buoys 2581, 2582 and 2587 from 29 October (JD 303) to 30 November (JD 335). During this period, the atmospheric flow in the southern Beaufort Sea was dominated by high pressure in the Arctic Ocean, resulting in persistent winds from the east. The average surface wind, as estimated from the pressure distributions of Thorndike and Colony (1981) was 8 ms^{-1}. The offshore buoys, 2587 and 2581 (Figures 3-2a and 3-2b), moved parallel to the coast at approximately 200 km offshore at average speeds of 0.13 ms^{-1} and 0.21 ms^{-1} respectively. Both of these buoys moved in 9/10 to 10/10 FY/YNG ice, although the paths were a short distance from and parallel to the 10/10 OLD pack ice. The movement of the inshore buoy (2582) shown in Figure 3-2b was more complicated, possibly being affected by its proximity to the coast (< 50 km) and the Mackenzie River. During one remarkable episode (16 November, JD 321, to 22 November, JD 327) the buoy moved rapidly to the west at speeds of up to 0.85 ms^{-1}, with an average of 0.60 ms^{-1}. This movement occurred in 9/10 to 10/10 YNG/FY ice.

All three buoys continued transmitting positions well into 1982 with rather sluggish motions being interspersed with periods of no motion.

Histograms of percent relative frequency of speed and direction are presented for 2581, 2582, 2587, and 2589 in Figures 3-3a and 3-3b; they are arranged so that Figure 3-3a relates to the buoys whose tracks are shown in Figure 3-2a, and Figure 3-3b to Figure 3-2b. The speeds and directions were calculated from the filtered records sampled at 12-hour intervals. The calculations were made for the entire record length, without regard to the sea ice environment, or whether (for 2581 and 2582) the drogue was indicated as on. As anticipated from the trajectory plots, the dominant direction for all buoys except 2589 was westward. For all buoys the 12-hour speeds from the filtered records were primarily less than 0.20 ms^{-1}. The speed of 2582 was 0.10 ms^{-1} or less 59% of the time. It is likely that these low speeds reflect its movement in the near shore ice environment as well as the period during which its drogue was in contact with the bottom. During the winter the buoy was motionless for extended periods.

3.3 Winter 1980-1981

During the winter of 1980-1981, six TAD's were deployed onto sea ice in the Arctic Ocean as part of three independent Coast Guard research projects. Two (2585 and 2586) were deployed at approximately the same location near the CANMAR drilling sites north of the Tuktoyaktuk Peninsula as part of the R&DC Arctic Oil Spill Research Project. Three platforms (2577, 2578, and 2579) were set onto sea ice as part of the R&DC Ice Research Project (now discontinued). The data from these three buoys, which were fitted with barometers, are reported in detail in Thorndike et al. (1982). Finally, one platform (2619) was air-dropped from a Coast Guard HC-130 onto sea ice northeast of Wrangel Island in support of the USCGC POLAR SEA 1981 Drift Project (Shuhy, 1981). The position data from 2619 are reported, in part, in Shuhy (1981).

The trajectories of five of the platforms (X marks the launch site) are presented in Figure 3-4. Platform 2585 provided only eleven days of position data, during which it moved only a short distance from its deployment location; its track is not plotted.

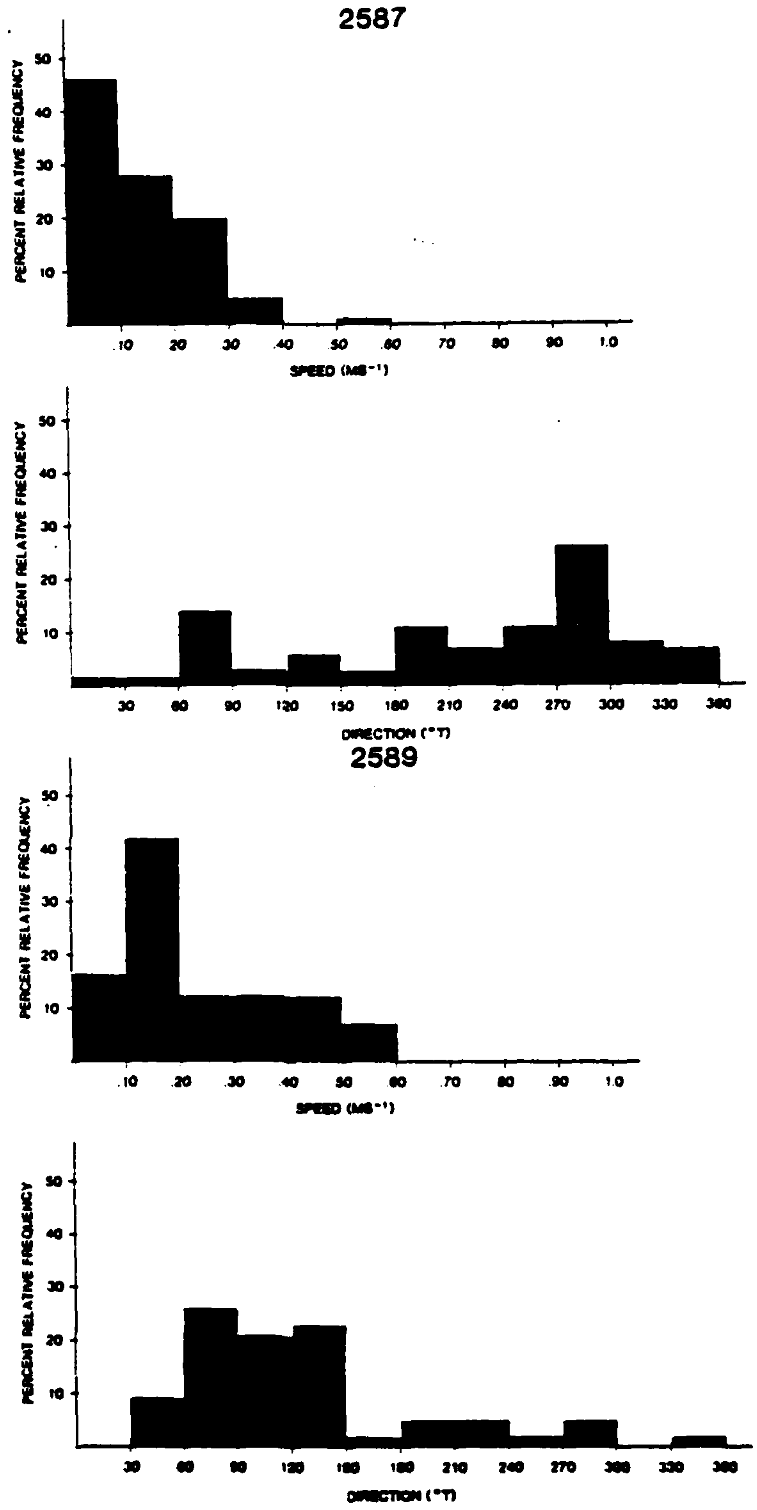

FIGURE 3-3a. Percent Relative Frequency of Speed and Direction for Buoy 2587 and Buoy 2589. Constructed from filtered records sampled at 12-hour intervals.

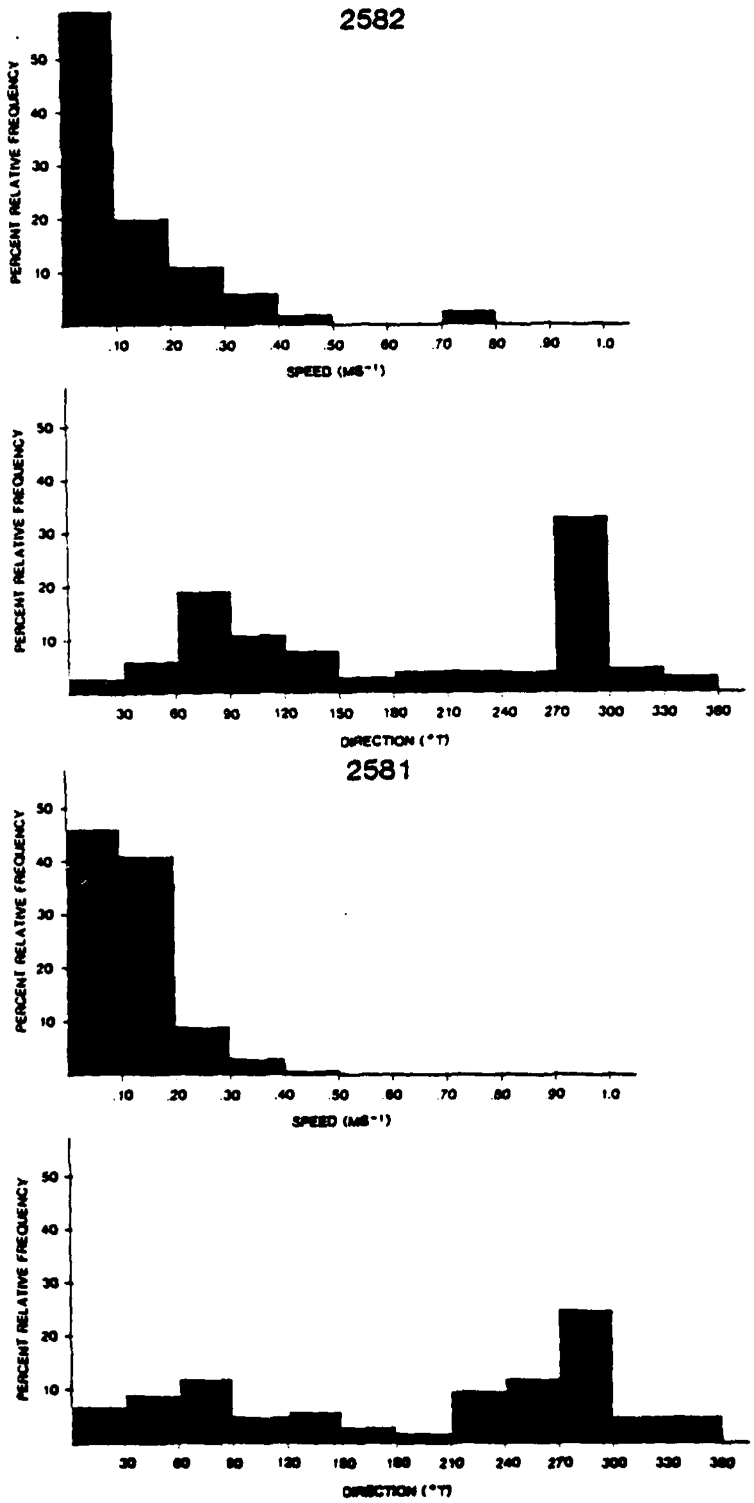

FIGURE 3-3b. Percent Relative Frequency of Speed and Direction for Buoy 2581 and Buoy 2582. Constructed from filtered records sampled at 12-hour intervals.

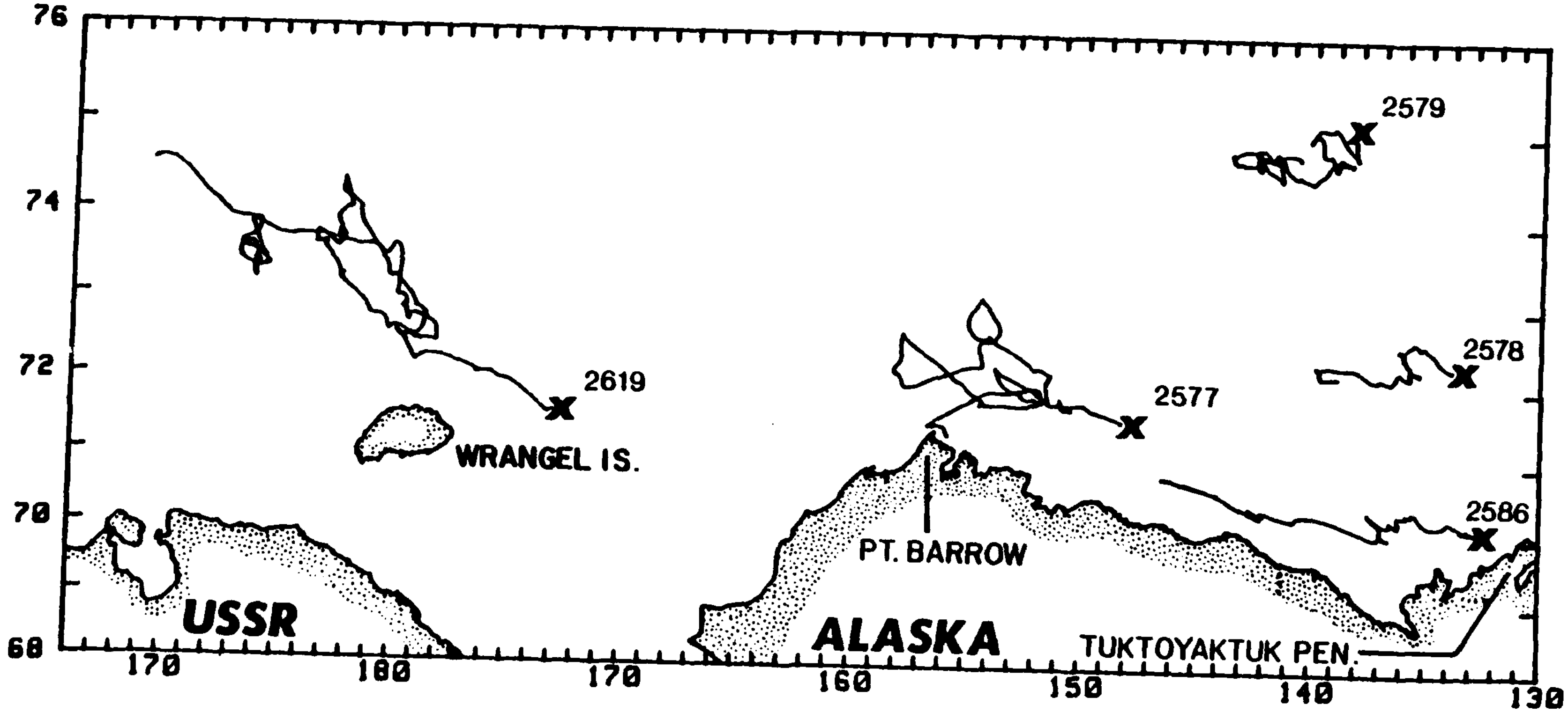

FIGURE 3-4. Trajectories of Platforms Deployed onto Sea Ice in the Winter 1980-1981. The deployment locations are marked with an X. Data Summaries for these Platforms are Presented in Tables 3-2 and 3-3. Detailed plots of the platform trajectories are presented in the following four illustrations.

The net platform motion shown in Figure 3-4 is primarily westward and north-westward (2619), which is consistent with the clockwise motion of the Beaufort Sea Gyre (Thorndike and Colony, 1980). However, the individual platform trajectories, shown in detail in Figures 3-5 through 3-8, indicate complex movement characterized by reversals in direction and periods of rapid motion interspersed with sluggish or no motion.

Platform 2586 (Figure 3-5) was deployed onto FY ice on 8 December (JD 343) 1980 and it provided 213 days of position data, during which its net motion was to the west. Its track was characterized by frequent and extended intervals of no motion (eg. JD 51-58, 114-128, and 156-163). This feature was unique to 2586. The others moved sluggishly at times, but only rarely were they motionless for more than a few days. The horizontal shear stresses related to the proximity of the coast is a possible explanation for this behavior. Along the track of 2586 there were also periods of rapid motion, for example, from 20-27 March (JD 79-86) 1980 during which it moved at speeds of up to 0.40 ms^{-1} from the Mackenzie Bay area to the Alaskan border. It ceased transmitting on 9 July (JD 190) 1980 two weeks after it reversed direction and retraced a portion of its westward track.

The track of 2586 is particularly noteworthy because it was placed on sea ice in Canadian offshore oil fields and it moved rather directly into U.S. waters. It spent nearly half of its transmission life west of the Canadian border, and, more important, it was there during summer break up. It is during break up that oil from sea ice contaminated during an oil spill could be released into open water.

The remaining four TAD's were deployed within thirteen days of each other in widely separated locations. Platforms 2579 and 2578 (Figure 3-6) were deployed considerably to the north of the launch site of 2586 on 11 April (JD 101) and 16 April (JD 106) respectively. The northern platform (2579) provided 136 days of position data, while 2578 transmitted positions for 83 days. Although a detailed analysis of the trajectories has not been made, there were periods during which the two trajectories appear to be coherent. The 12-hour speeds rarely exceeded 0.15 ms^{-1}, and equally rare were periods of no motion.

The path of 2577 (Figure 3-7), deployed on 6 April (JD 96) 1981, is spectacularly convoluted. Its motion was also characterized by several periods in which the 12-hour speeds exceeded 0.20 ms^{-1} and speeds of up to 0.40 ms^{-1}. Its path culminated by it nearly beaching on Pt. Barrow on JD 283.

Buoy 2619 was deployed to the east of Wrangel Island on 3 April (JD 93) 1980 and provided ten months of position data which are plotted in Figure 3-8. Its motion was characterized by a large north-westward net motion, with one major counter-clockwise loop. There were several periods during which the 12-hour speed exceeded 0.20 ms^{-1}, and only infrequently was it motionless for more than 12 hours.

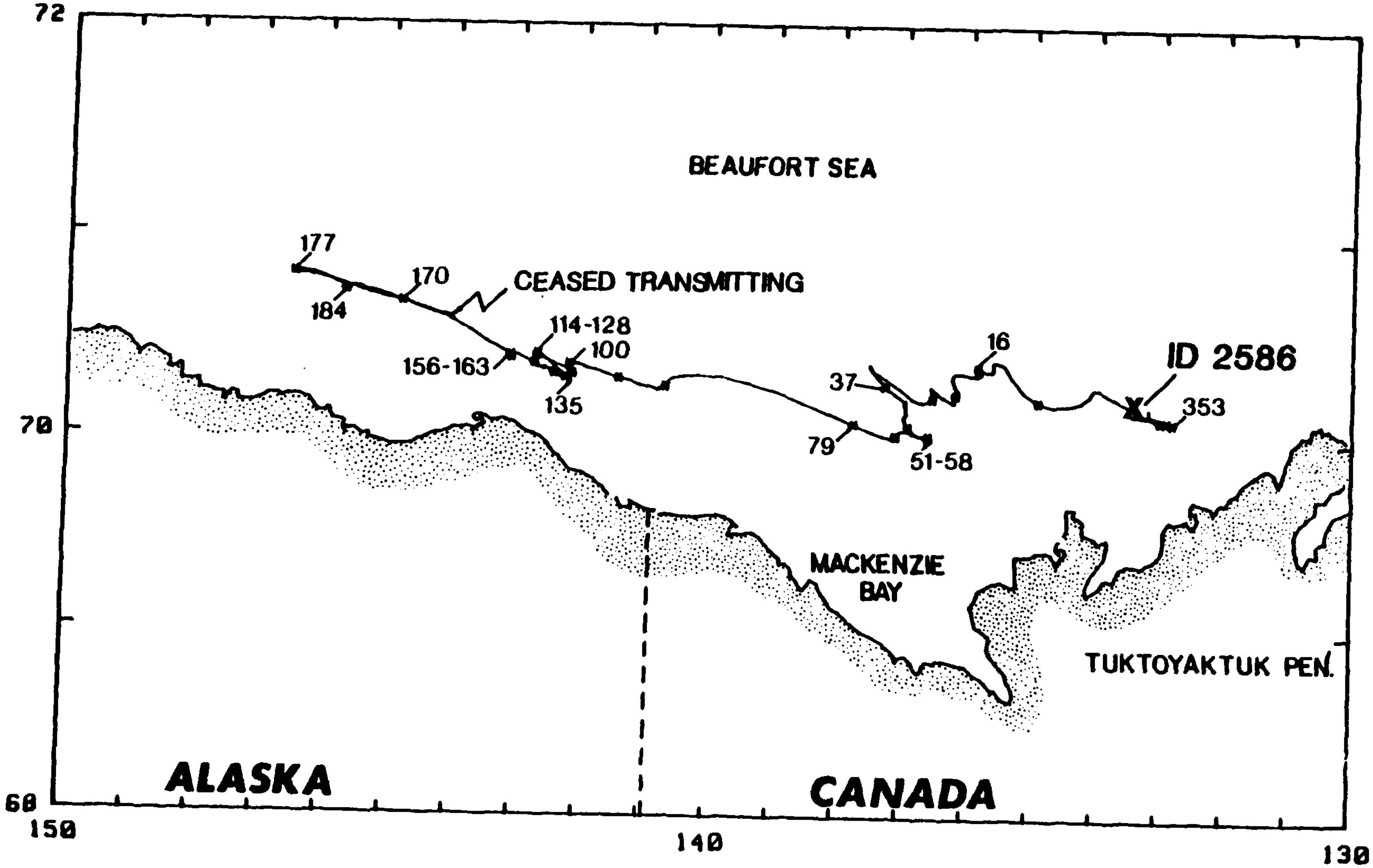

FIGURE 3-5. Filtered Trajectory for Platform 2586 Deployed on 8 December (JD 243) 1980. The approximate position of the launch site is marked by an "X". Dates are given in Julian Dates; asterisks are plotted at seven-day intervals.

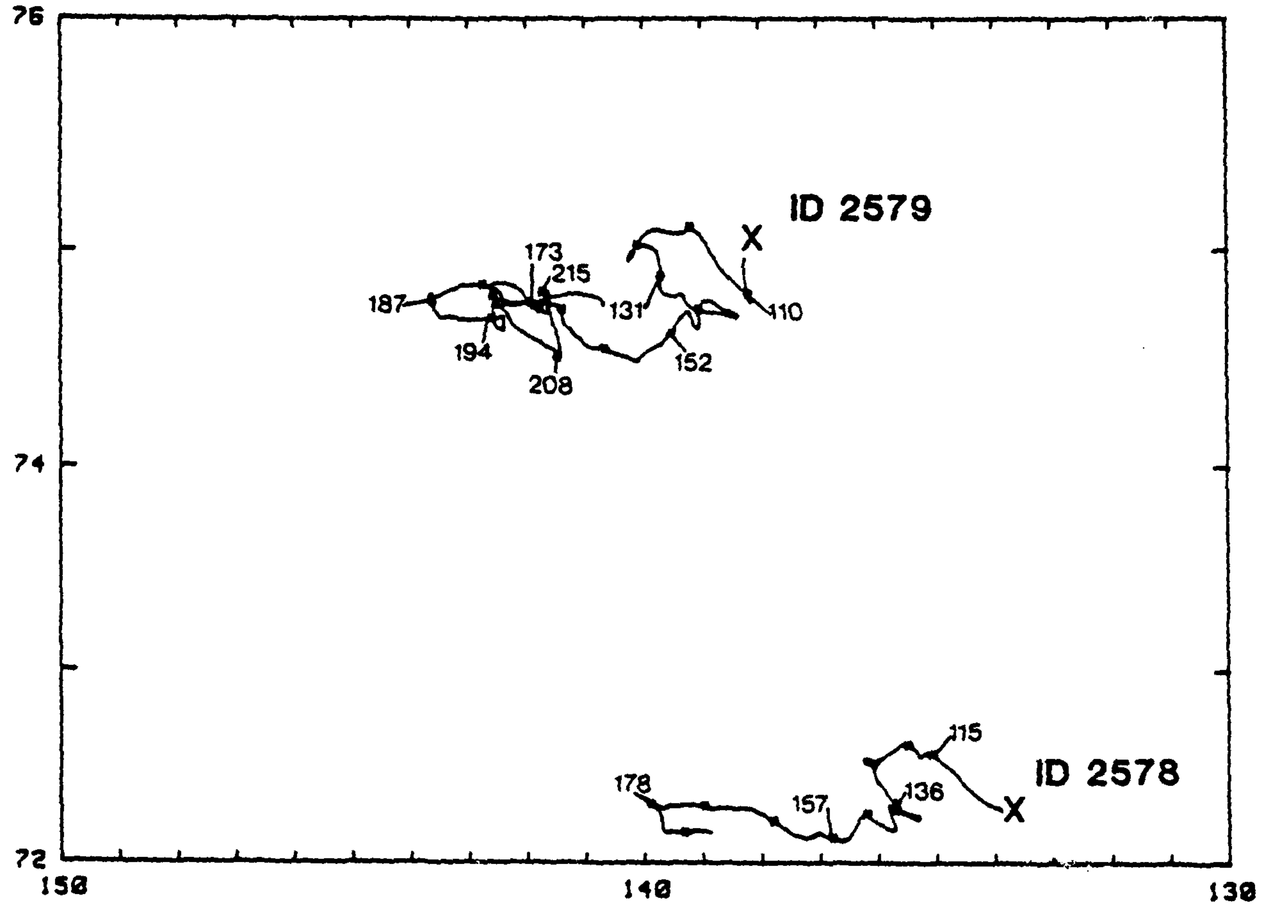

Figure 3-6. Filtered Trajectories for Platforms 2578 and 2579 Released on 16 April (JD 106) 1981 and 11 April (JD 101) 1981 Respectively. The approximate location of the deployment site is marked with an "X". The dates are given in Julian Days; asterisks are plotted at seven-day intervals.

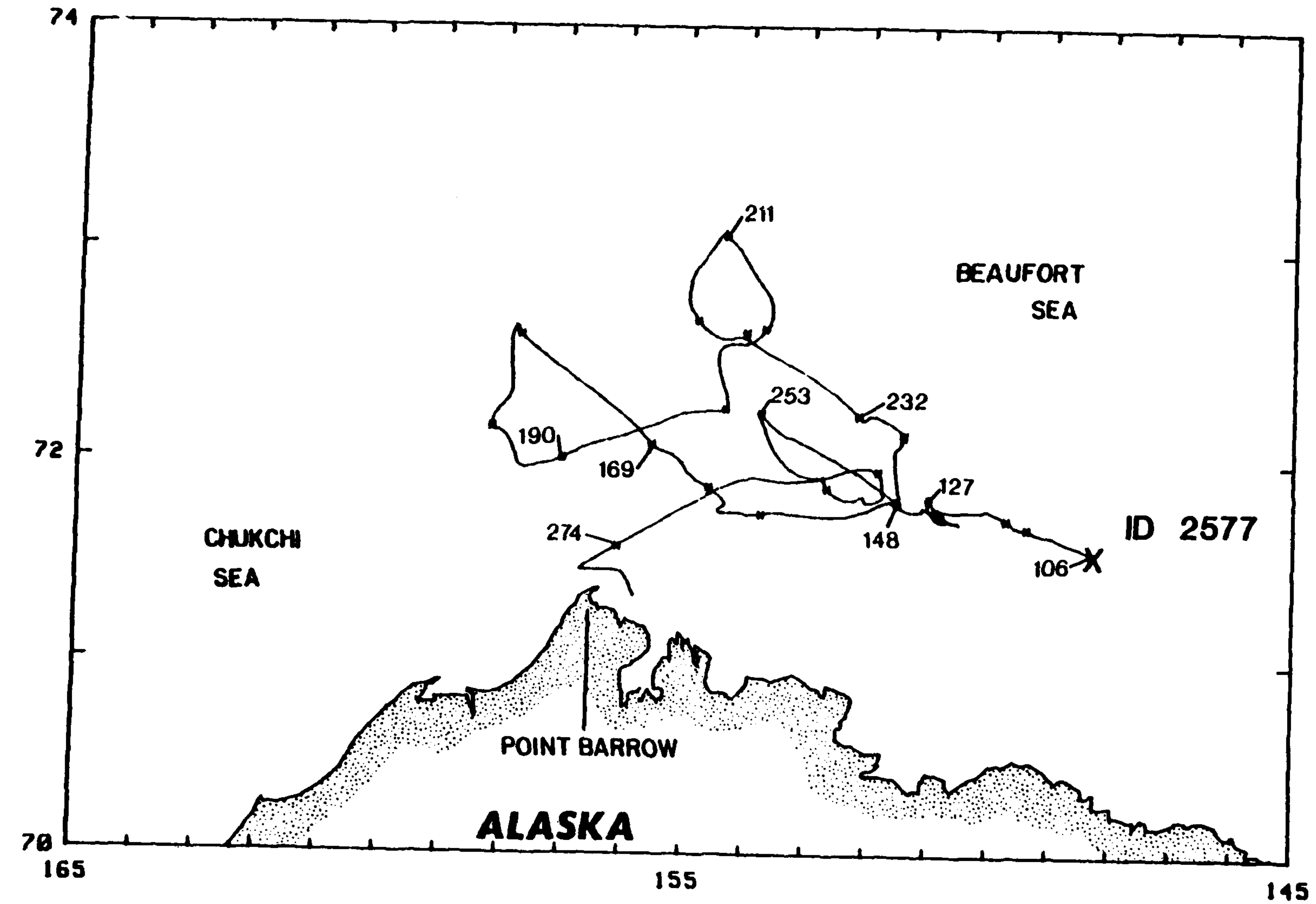

FIGURE 3-7. Filtered Trajectory for Platform 2577 Deployed on 6 April (JD 96) 1981. The approximate position of the release site is marked with an "X". The dates are given in Julian Dates; asterisks are plotted at seven-day intervals.

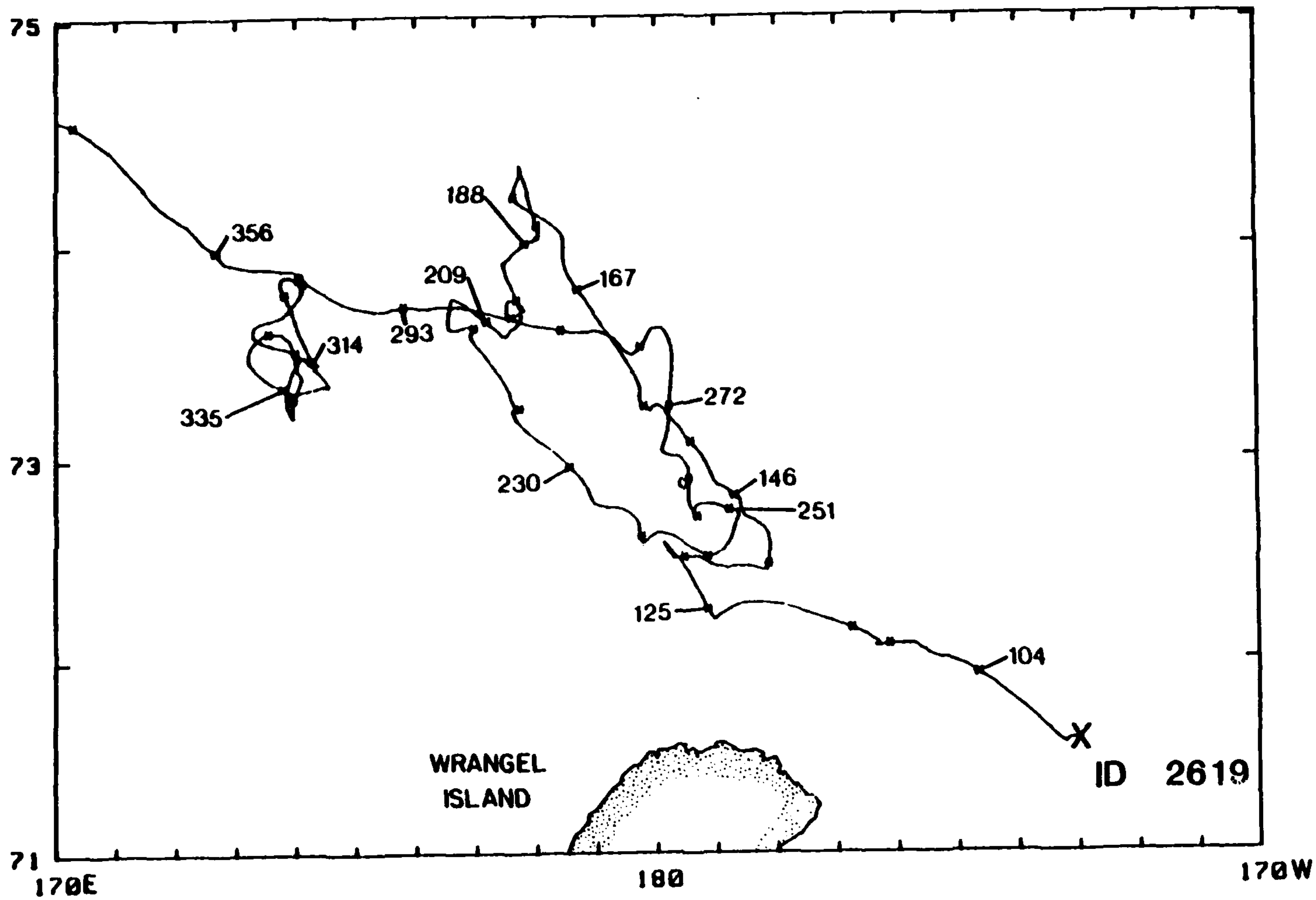

FIGURE 3-8. Filtered Trajectory for Platform 2619 Deployed on 3 April (JD 93) 1981. The approximate position of the release site is marked with an "X". The dates are given in Julian Days; asterisks are plotted at seven-day intervals.

3.4 Summer 1981

The effort in summer 1981 again focused on the temporal variability of the surface flow field. As in 1980, eight buoys, four with PRL hulls and four with CANMAR hulls, were released into ice-free water over a three-week period beginning on 15 August (JD 227). The PRL hulls were fitted with wind speed indicators; the wind data were transmitted with the positions via the ARGOS System. None of the buoys had drogues. On two occasions during the release period, buoys of different hull types were released concurrently to compare their response. On the first date (15 August, JD 227) three buoys, two with PRL hulls and one with a CANMAR hull, were released at the same time. On the second occasion (22 August, JD 234) one of each type was released.

Of the eight buoys launched during 1981, one malfunctioned shortly after deployment, and another was apparently recovered by a vessel; the trajectories of the remaining six buoys are plotted in Figure 3-9(a, b and c).

The five buoys released in the first week (15-22 August, JD 227-234, Figures 3-9a and 3-9b) remained in the general vicinity of the launch area under light and variable winds. This condition persisted until 29 August (JD 241) when three days of vigorous winds, primarily from the northwest, drove three of the five buoys ashore on the Tuktoyaktuk Peninsula, and the remaining two into Liverpool Bay. The average wind speed measured on buoy 2601 during 29 August (JD 241) to 1 September (JD 244) was 11 ms^{-1}. This figure agrees well with an independent estimate of the surface wind speed calculated from the atmospheric pressure distributions presented in Thorndike et al. (1982); the orientation of the isobars was used to estimate the wind direction in the study area.

For the four buoys which drifted for the entire northwest wind event (one beached early in the three day period), the average shoreward speed was 0.37 ms^{-1}. For an 11 ms^{-1} wind speed, this results in buoy speeds of 3.4% of the surface wind speed.

The surface currents documented by the eastward buoy movements are remarkably consistent with the flow field proposed by MacNeill and Garrett (1975) for persistent and vigorous (≥ 12 ms^{-1}) northwest winds. This current regime, based on observations and extrapolations, provides for a general surface water movement southeastward toward the coast which turns parallel to the coast about 10 km offshore. They estimate a mean surface current speed of 0.35 ms^{-1}, and also propose a circulation into Liverpool Bay. One could have accurately predicted the buoy motions based on the current field of MacNeill and Garrett.

Buoy 2604, released on 4 September (JD 247) well after the northwest winds had subsided, shows quite a different behavior (Figure 3-9c). It remained in the general launch vicinity for six weeks, whereupon it commenced a persistent and, at times, rapid (> 0.50 ms^{-1}) northwest and westward movement (25 October, JD 298) under the influence of east winds. During this period, the buoy was in 9/10 to 10/10 YNG ice; it ceased transmitting shortly after it entered an area of 9/10 to 10/10 OLD/FY ice on 4 November (JD 308).

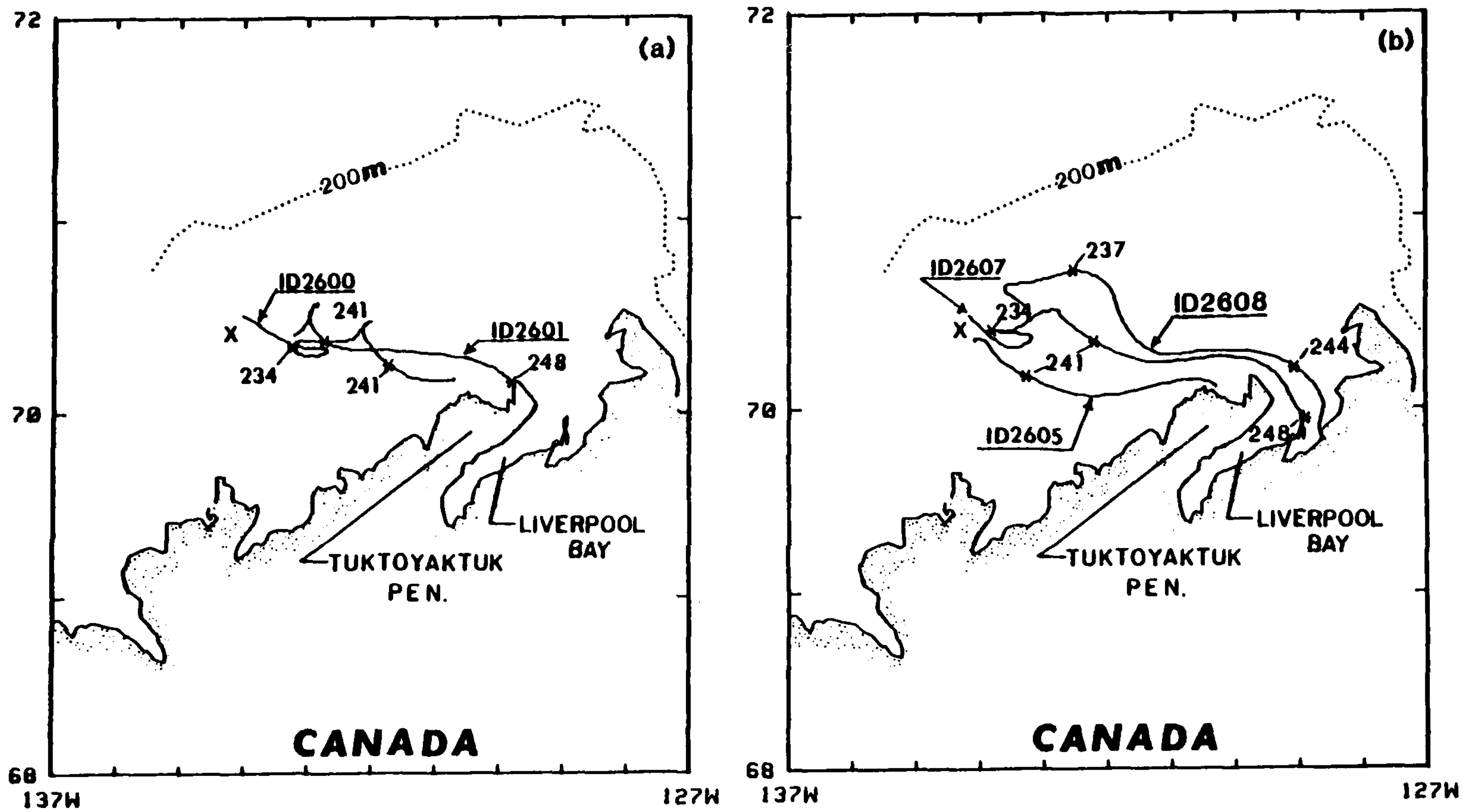

FIGURE 3-9. Filter Trajectories for Buoys Released in 1981. (a) Buoy 2600 released 15 August (JD 227) and Buoy 2601 released 22 August (JD 234); (b) Buoy 2605 released 22 August (JD 234), Buoy 2607 released 15 August (JD 227), and Buoy 2608 released 18 August (JD 230); (c) Buoy 2604 released 4 September (JD 247). Dates are given in Julian Days; asterisks are plotted at seven-day intervals. Continued on next page.

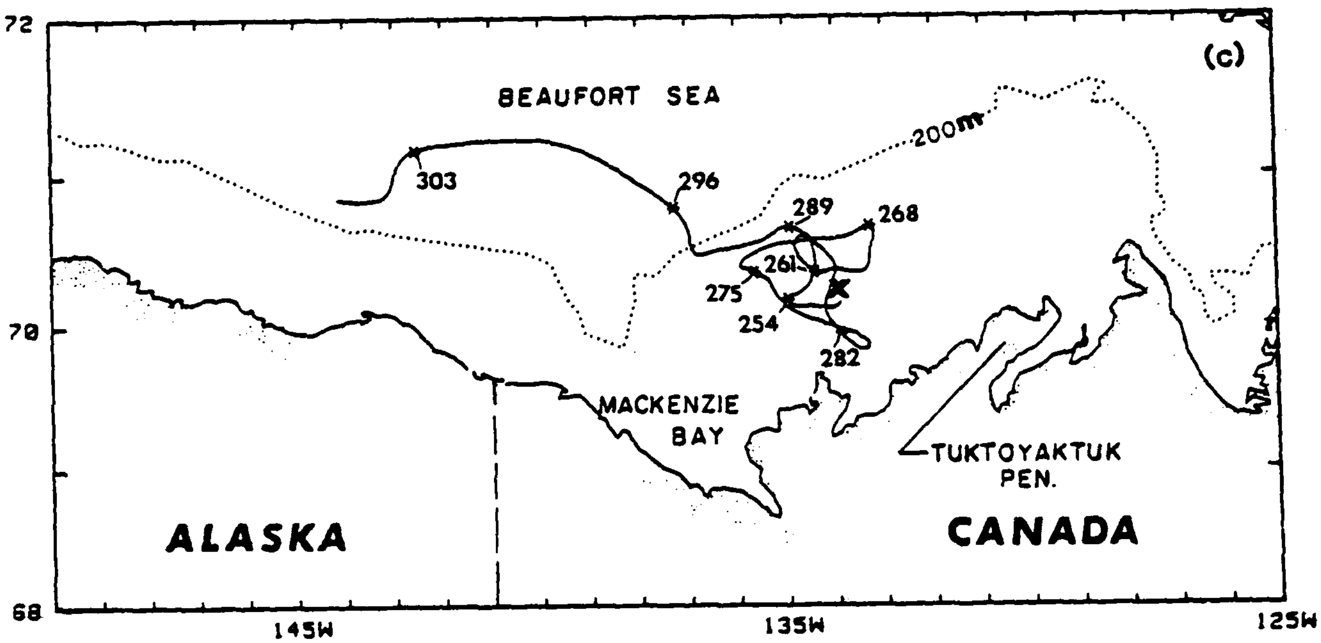

FIGURE 3-9 (Cont'd). Filtered Trajectories for Buoys Released in 1981. (a) Buoy 2600 released 15 August (JD 227) and Buoy 2601 released 22 August (JD 234); (b) Buoy 2605 released 22 August (JD 234), Buoy 2607 released 15 August (JD 227), and Buoy 2608 released 18 August (JD 230); (c) Buoy 2604 released 4 September (JD 247). Dates are given in Julian Days; asterisks are plotted at seven-day intervals.

Histograms of percent relative frequency of speed and direction for the buoys released in 1981 are presented in Figures 3-10a, 3-10b, and 3-10c. The figures are arranged so that the histograms in Figure 3-10a relate to the buoy tracks of Figure 3-9a, 3-10b to 3-9b, and 3-10c to 3-9c. With the exception of buoy 2604 (Figure 3-10c), the dominant direction was eastward with the most frequently occurring speed in range of 0.10 to 0.20 ms^{-1}.

There was little apparent systematic difference in the movement of the PRL and CANMAR hulls. Figure 3-11 shows the velocity vectors, constructed from the filtered records sampled at 12-hour intervals, for the buoys released prior to the strong northwest winds. In the cases in which a buoy of each type was released concurrently, the buoys moved in a qualitatively similar manner. Regrettably, the effort to compare the movement of identical hulls with the concurrent movement of different hull types failed with the early demise of one of the PRL-hulled buoys released on 15 August (JD 227).

4.0 DISCUSSION AND CONCLUSIONS

The most striking feature of the buoy drift data is the dramatic interannual variability evident in the trajectories of the oceanographic drifters released during the three summers. Buoys deployed in essentially the same location and at the same time of the year traveled as far west as the Wrangel Island vicinity in the Chukchi Sea and as far east as the Parry Peninsula in Amundsen Gulf. Comparisons of the early buoy movement data and surface winds calculated from NMC atmospheric pressure distributions (Murphy et al., 1981) suggest that the buoy motions are closely related to local wind forcing. More detailed comparisons are presently being conducted using the pressure distributions determined by the University of Washington, Polar Science Center (e.g., Thorndike and Colony, 1981). Their efforts in deploying numerous satellite-tracked platforms with barometers on sea ice have vastly improved the quality of meteorological data in the Arctic Ocean.

Amid the pronounced interannual variability demonstrated by the oceanographic drifter trajectories, there is a thread of consistency. In all of the years there has been significant net westward movement evident in the buoy tracks. By far the most dramatic westward movement occurred in 1979; all of the buoys moved to the west, one approaching to within 50 km of Pt. Barrow (443). In 1980, three of the four buoy tracks showed a net westward motion, and one of these (2582) approached to within 10 km of the Alaskan coast. Even in 1981, with the spectacular eastward movement, the buoy released after the strong northwest winds had subsided (2604) had a net westward motion. It is not the intent to argue that these buoy motions reflect the movement of oil from potential spills, but rather to show that there can be significant westward net drift in the southeastern Beaufort Sea and that there is justification for the concern that the Alaskan coast could be affected by a major blowout during Canadian operations.

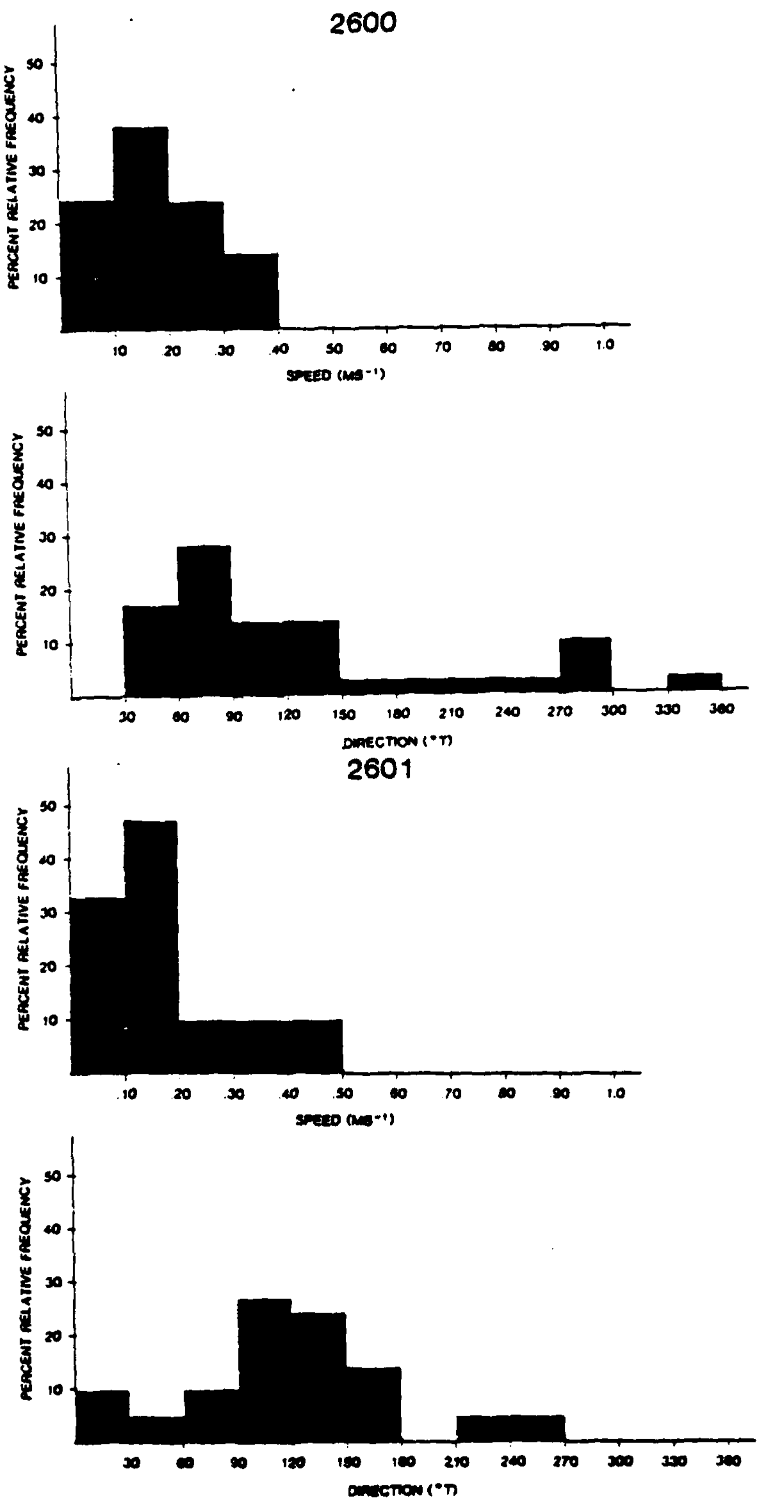

FIGURE 3-10a. Percent Relative Frequency of Speed and Direction for Buoys 2600 and 2601. Constructed from filtered records sampled at 12-hour intervals.

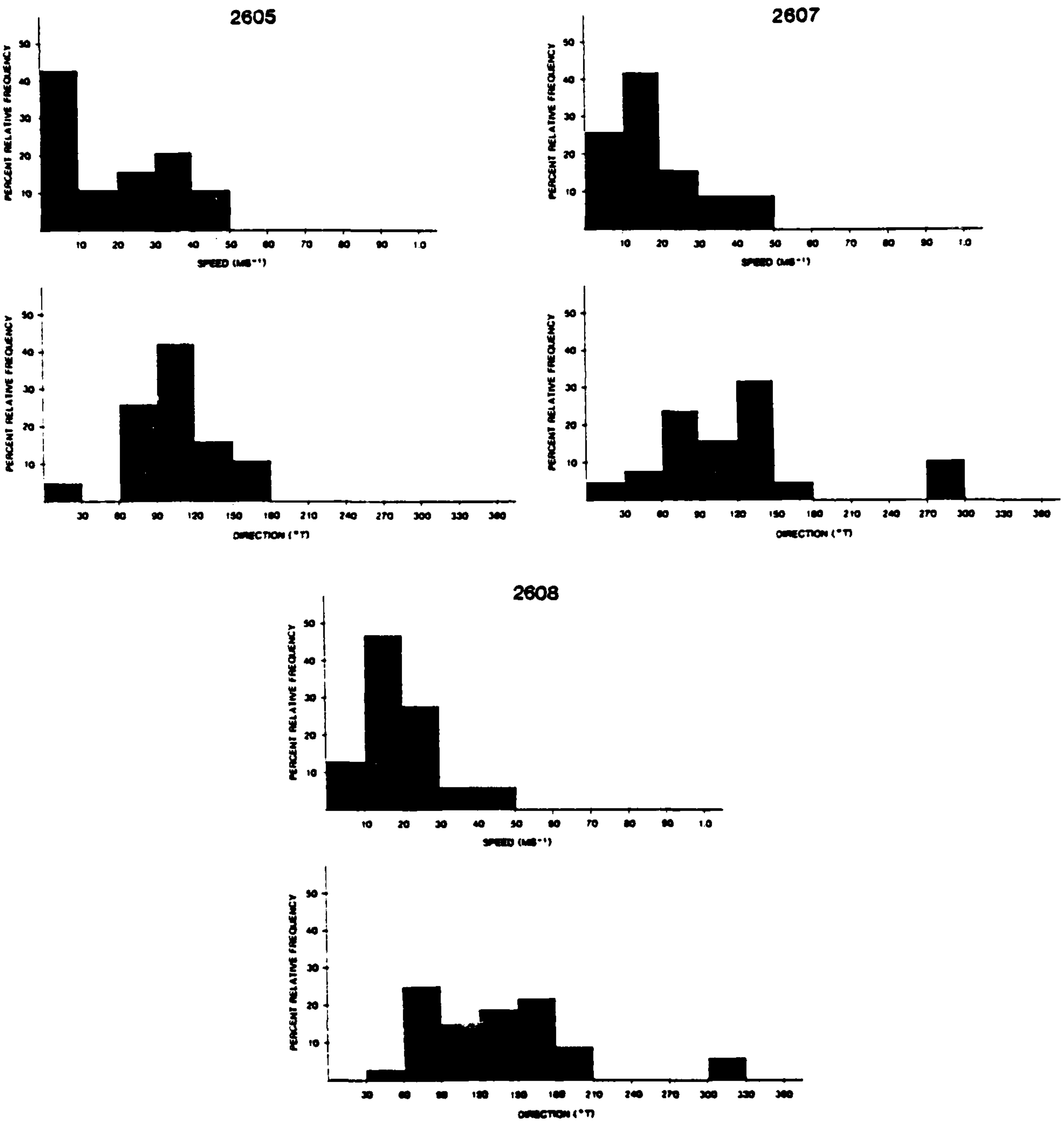

FIGURE 3-10b. Percent Relative Frequency of Speed and Direction for Buoys 2605, 2607, and 2608. Constructed from filtered records sampled at 12-hour intervals.

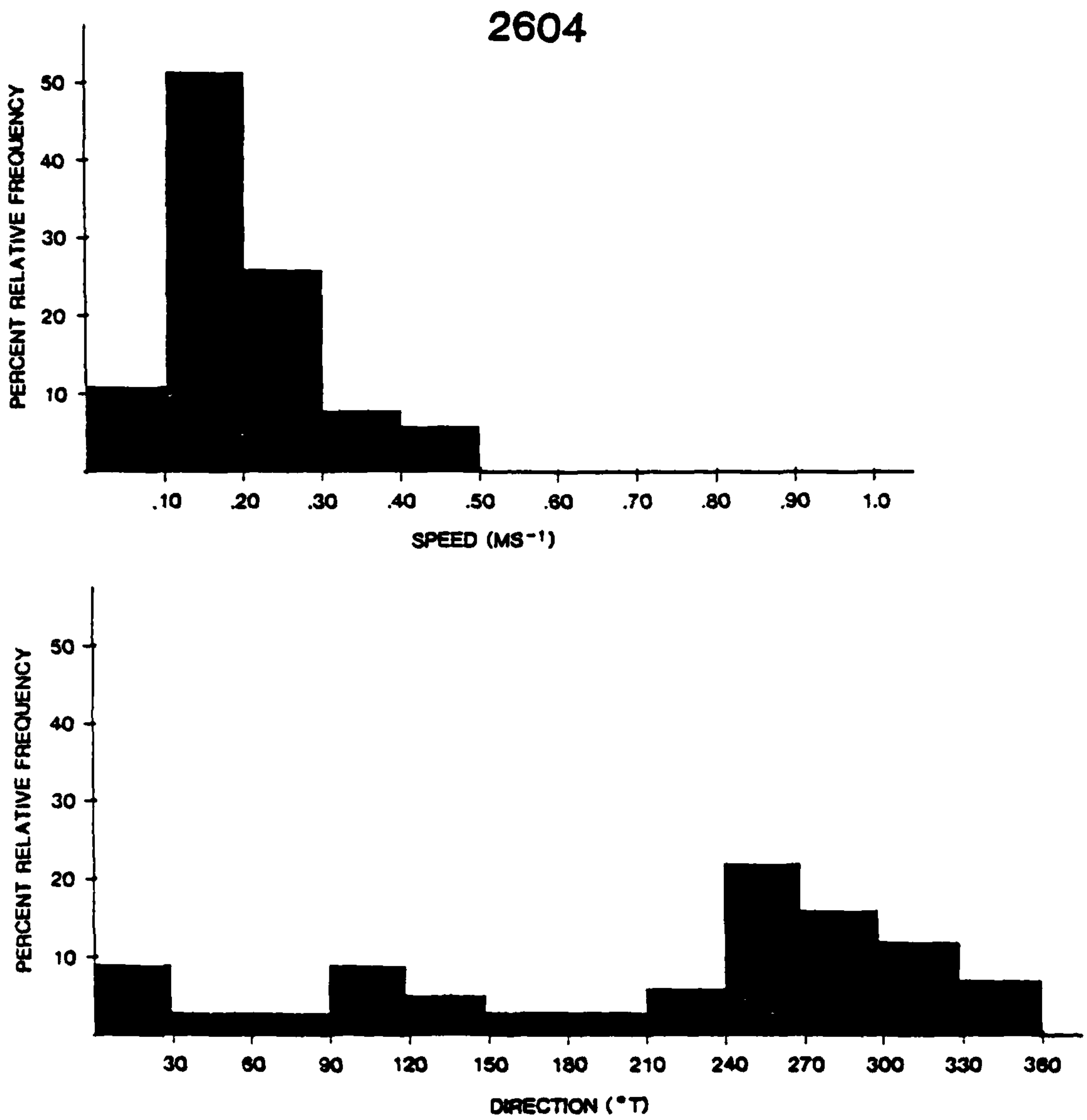

FIGURE 3-10c. Percent Relative Frequency of Speed and Direction for Buoy 2604. Constructed from filtered records sampled at 12-hour intervals.

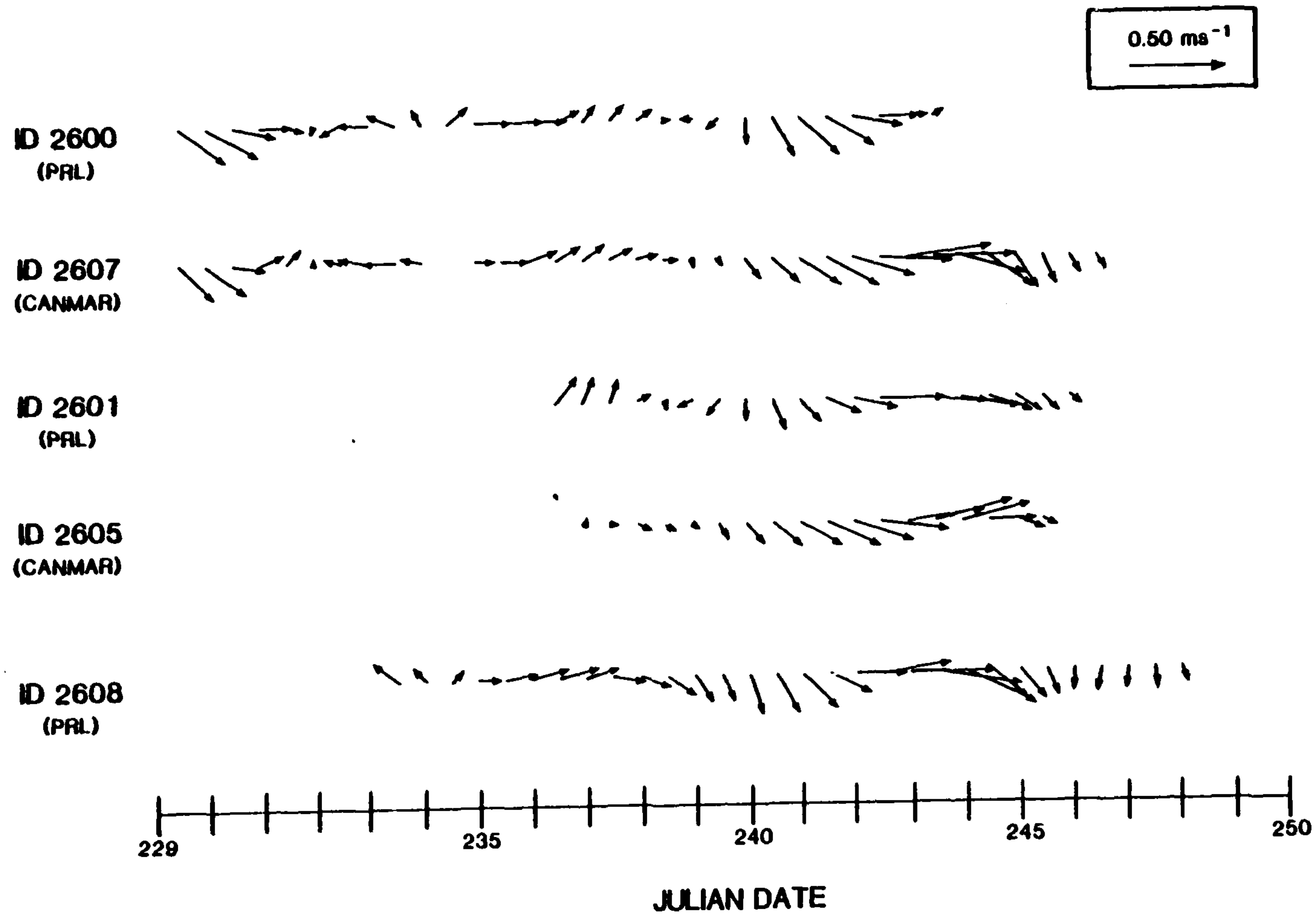

FIGURE 3-11. Velocity Vectors for 1981 Oceanographic Drift Buoys.

The eastward motion in the 1980 and 1981 oceanographic drifter trajectories provides strong support for the surface current regime proposed by MacNeill and Garrett (1975) for persistent northwest winds in the Tuktoyaktuk area. Northwest winds, usually associated with the passage of low pressure systems through the northern Beaufort Sea, are a common but not dominant summer wind condition in the study area. They are important because vigorous and persistent northwest winds cause rapid onshore movement of surface waters. The 1981 drift data, in particular, support the onshore motion and the development of a strong coastal current flowing northeastward along the Tuktoyaktuk coast, and eventually into Liverpool Bay.

In the summer of 1982 the R&DC Beaufort Sea drift study continued with the deployment of four oceanographic drifters (with CANMAR hulls) near Tuktoyaktuk. Each of the buoys provided substantial position data which are only partially analyzed at this time. These data will be presented in a future report.

The planned 1983 deployment involves the release of oceanographic drifters at two Beaufort Sea sites during the summer open water season. As in several previous years, CANMAR will deploy four buoys at their drill sites near Tuktoyaktuk. At approximately the same time, R&DC will deploy six undrogued PRL oceanographic drifters at sites offshore of Prudhoe Bay, Alaska. Specific release sites and dates have not yet been chosen. This effort will be conducted in cooperation with Alaska Clean Seas, a consortium of oil companies investigating oil spill countermeasures. This is the first R&DC buoy deployment in Alaskan waters, and it comes at a time when offshore exploratory drilling is increasing in the region. For example, in late 1983 Sohio plans to start drilling on an artificial island in the Mukluk structure 35-45 km offshore and only 55 km to the west of Prudhoe Bay (Oil and Gas Journal, 1983).

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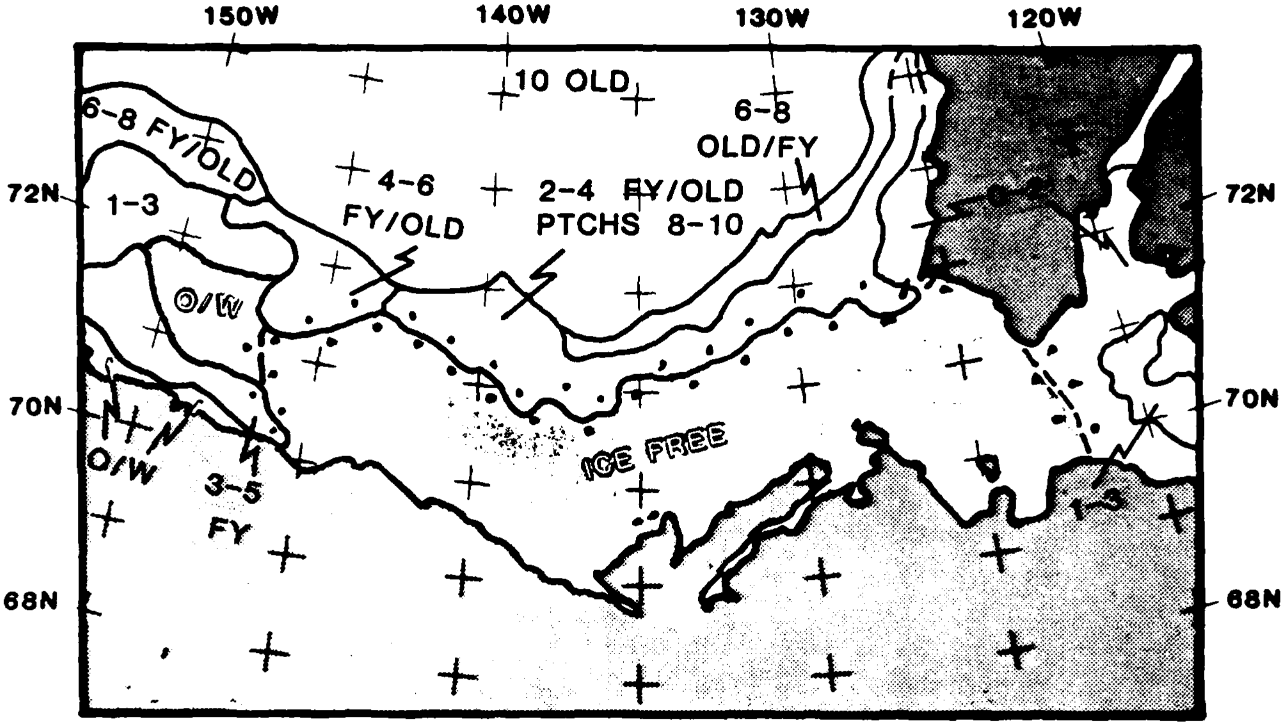
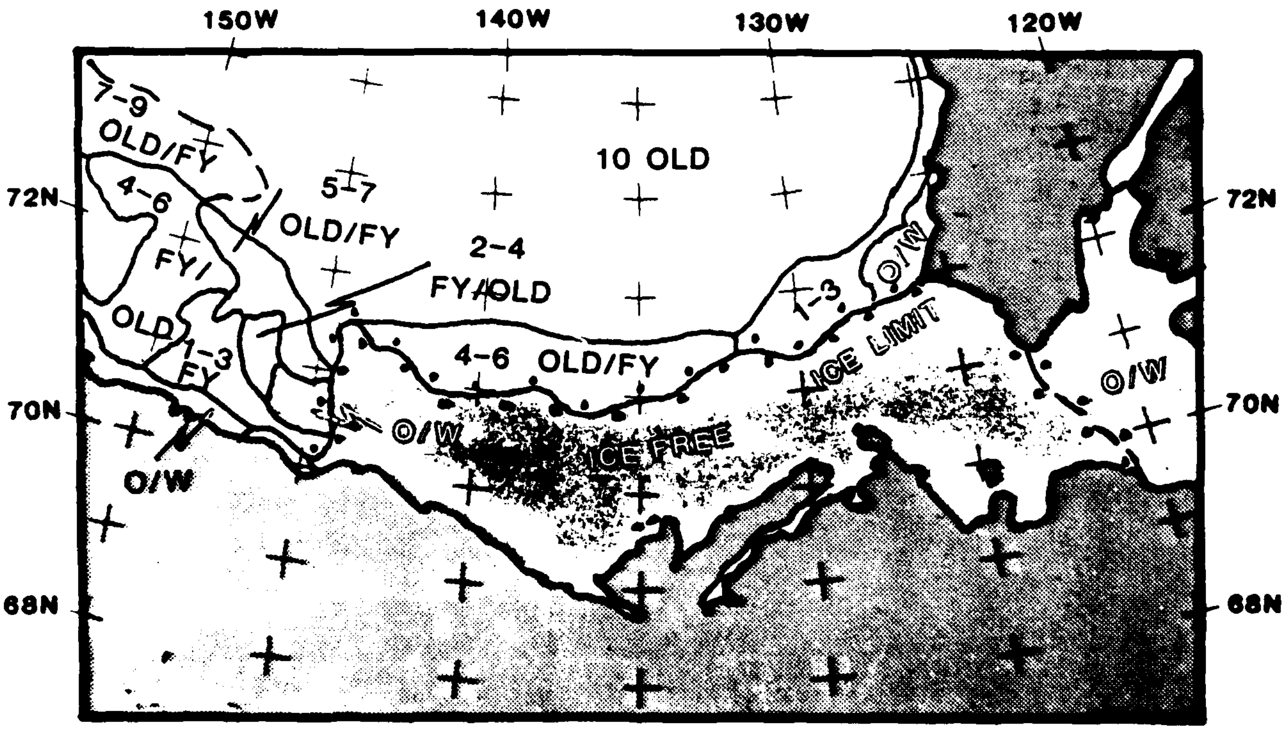
APPENDIX A

1980 Sea Ice Concentrations

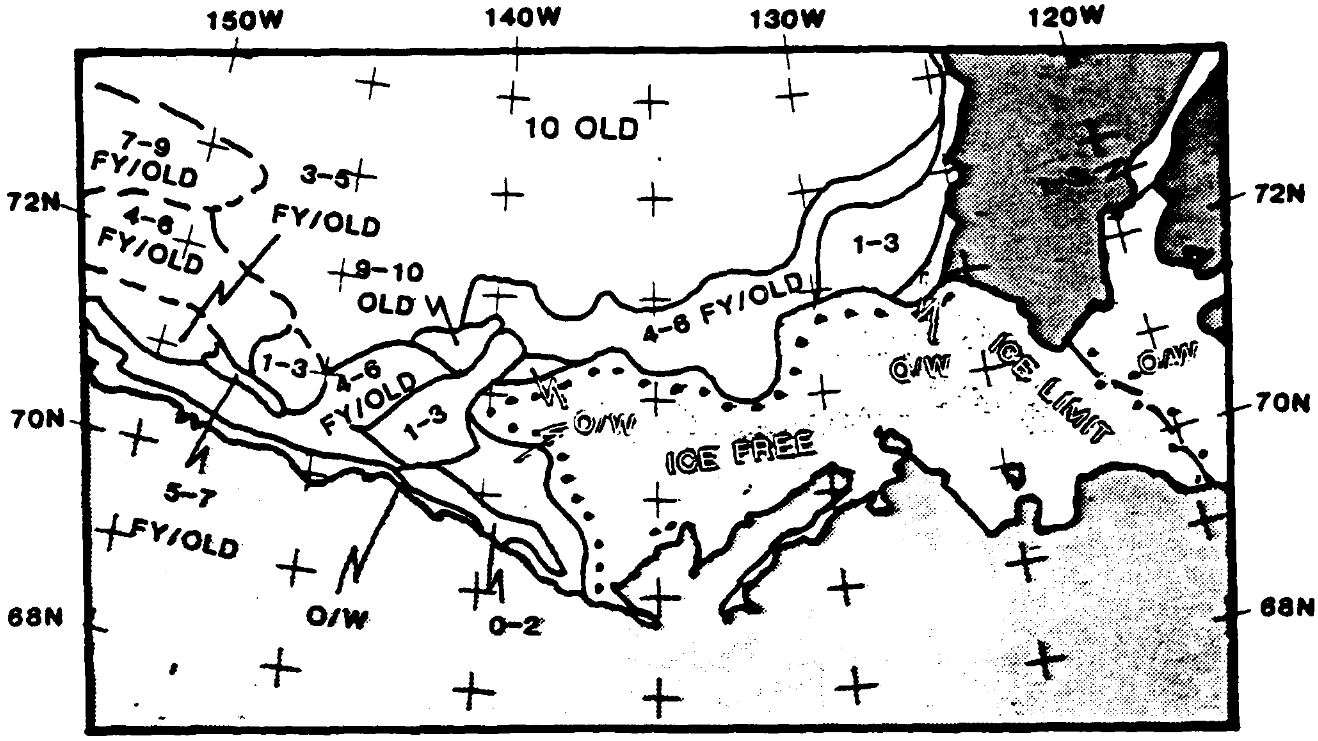
Weekly sea ice concentrations in the study area for the period 19 August - 4 November 1980.



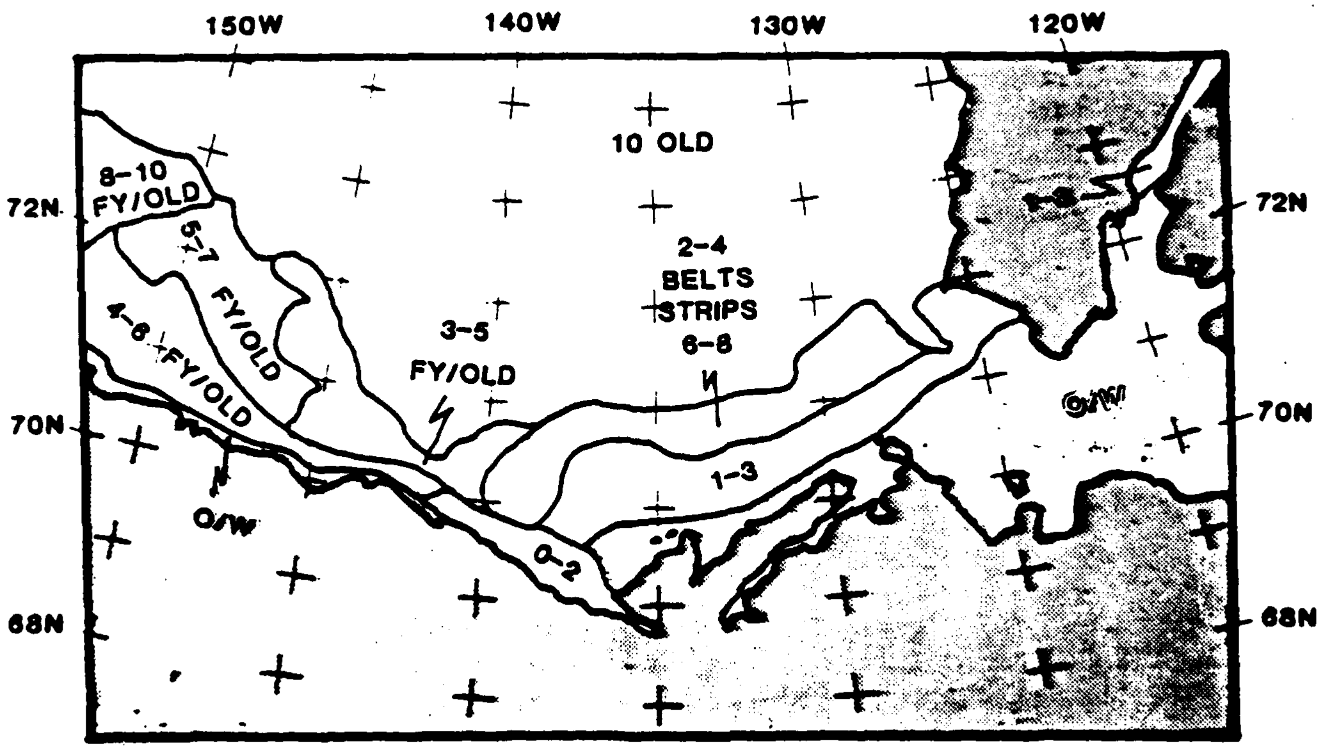
1. 19 AUG 1980



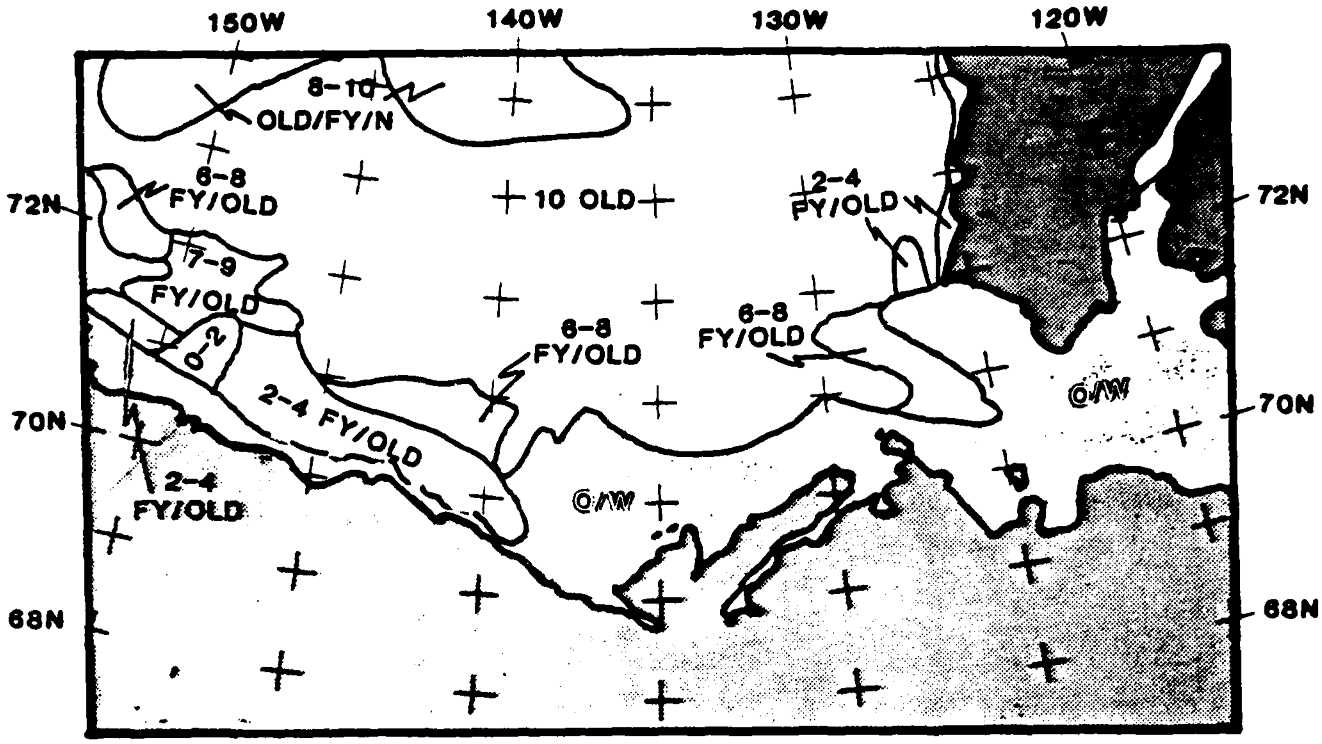
2. 26 AUG 1980



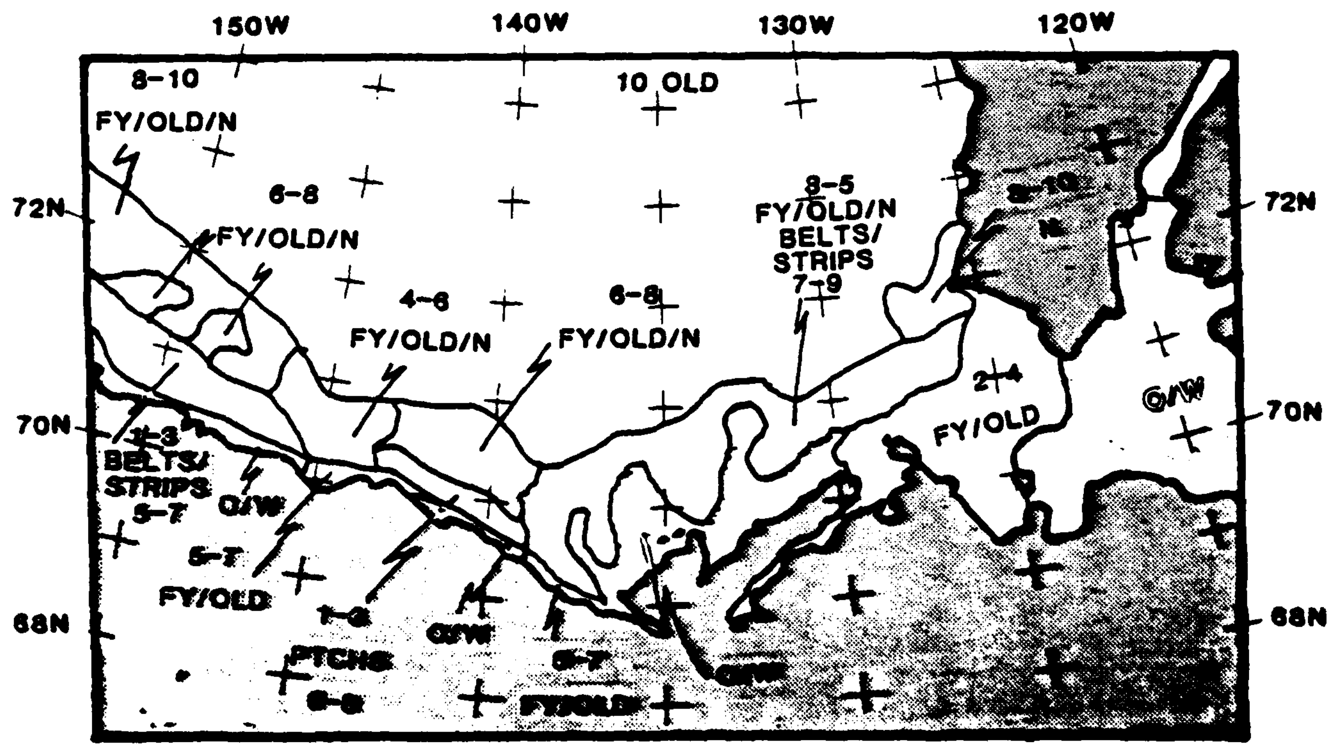
3. 2 SEP 1980



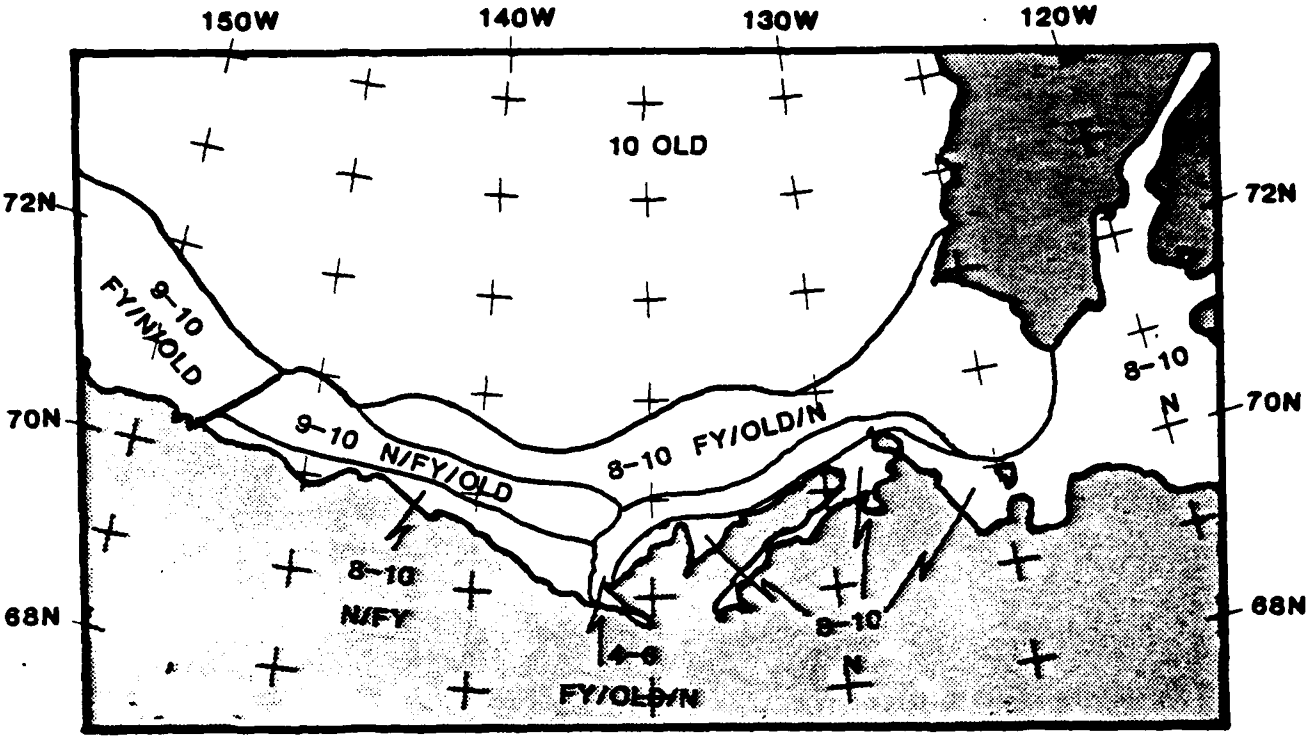
4. 9 SEP 1980



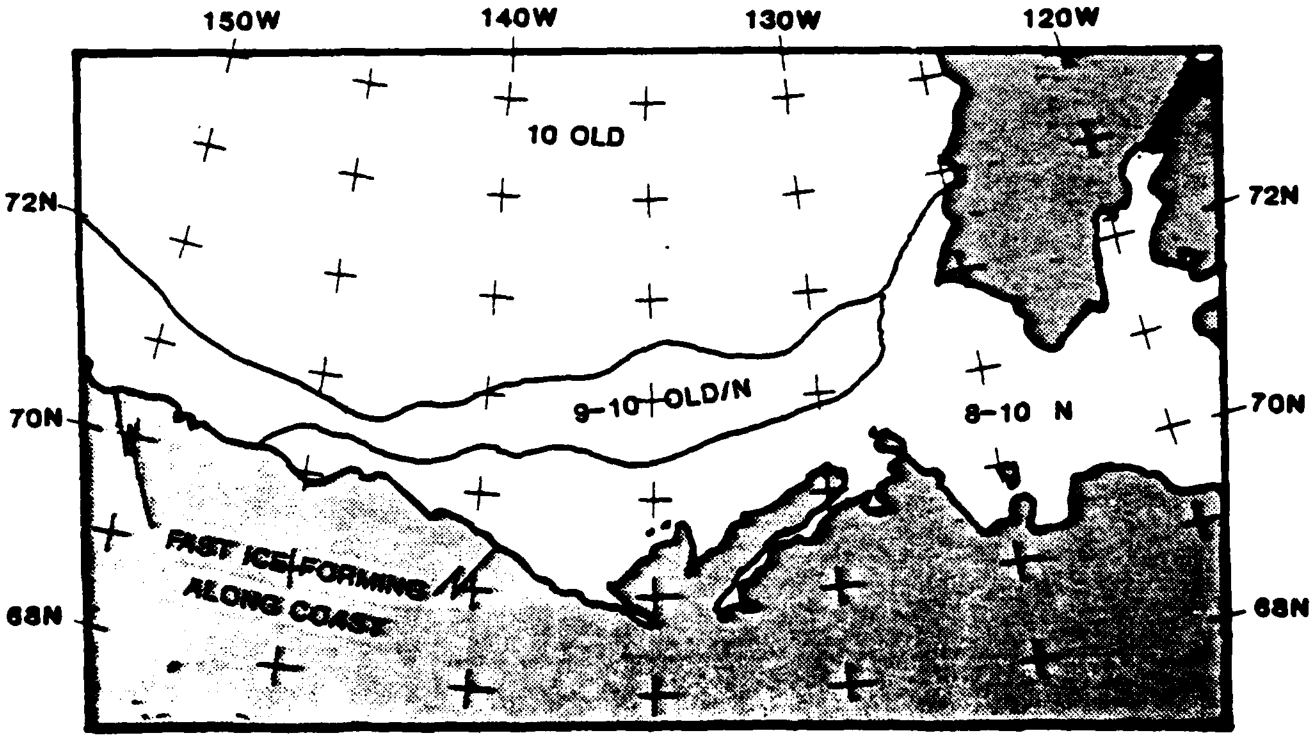
5. 16 SEP 1980



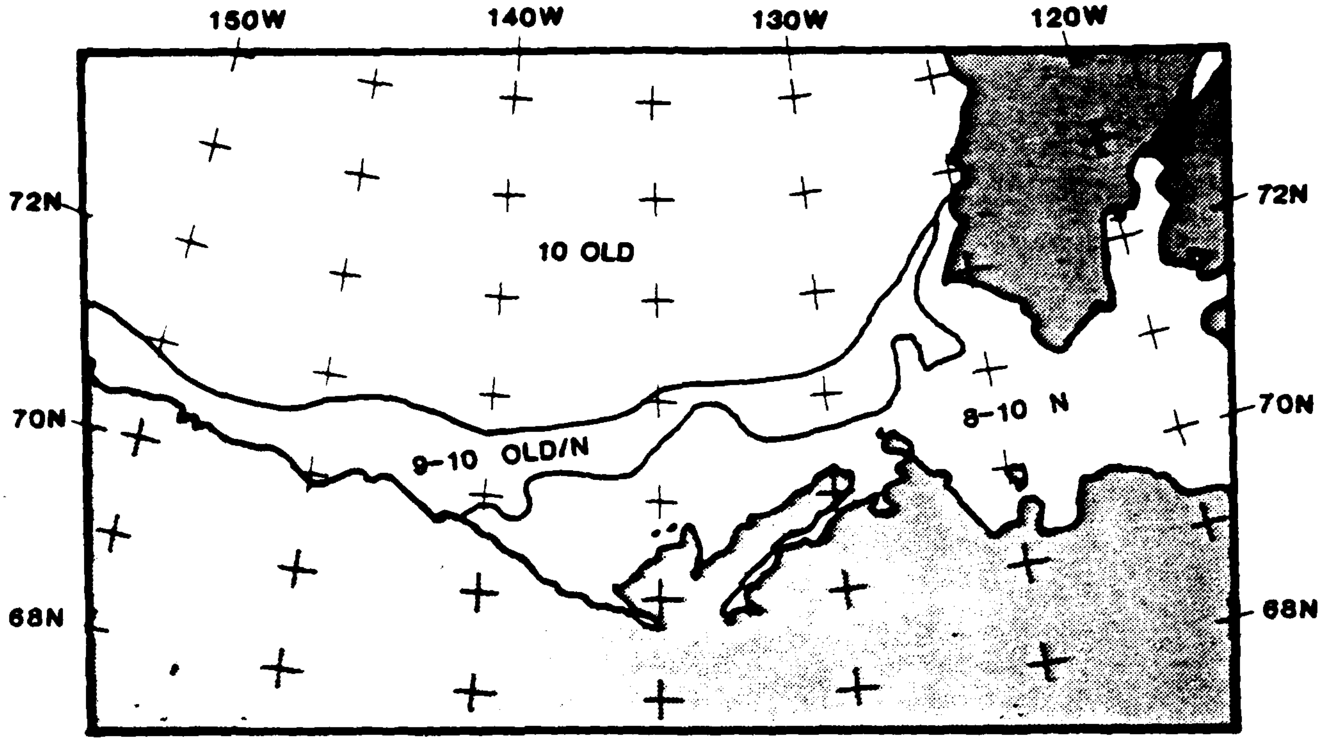
6. 23 SEP 1980



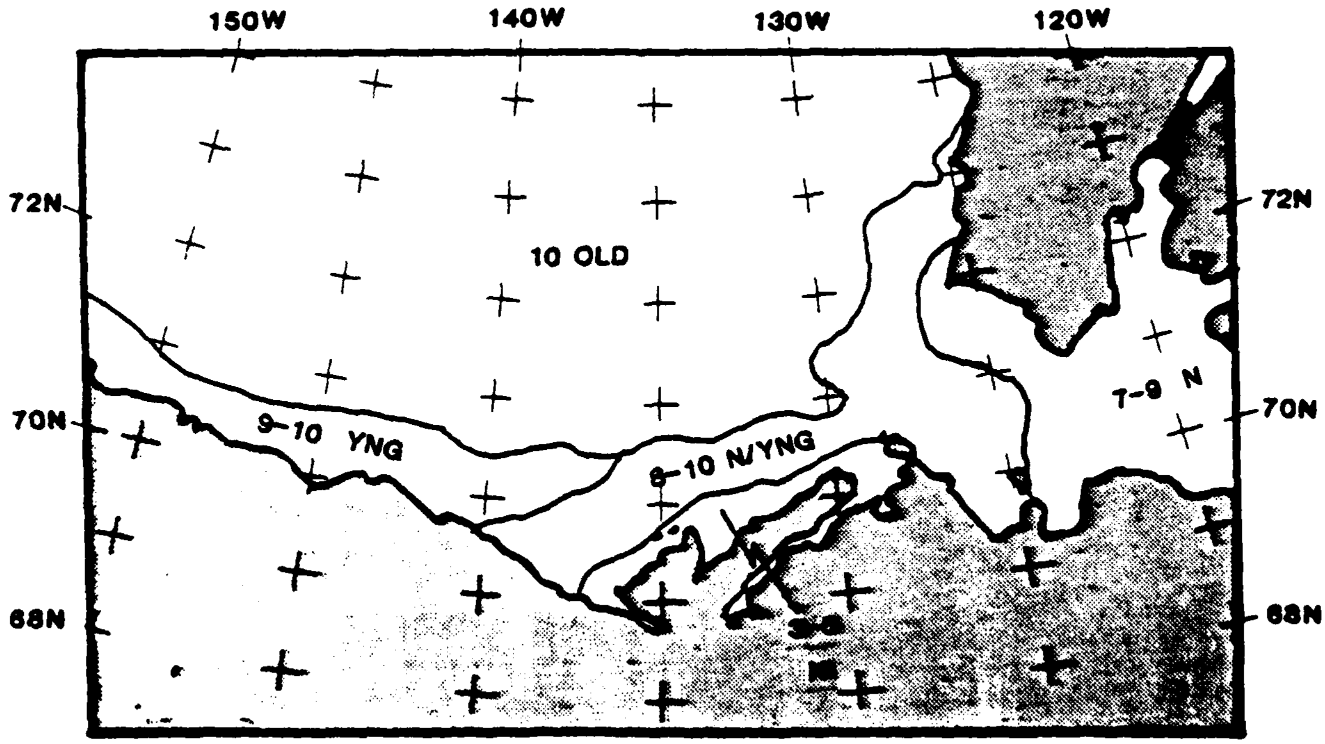
7. 30 SEP 1980



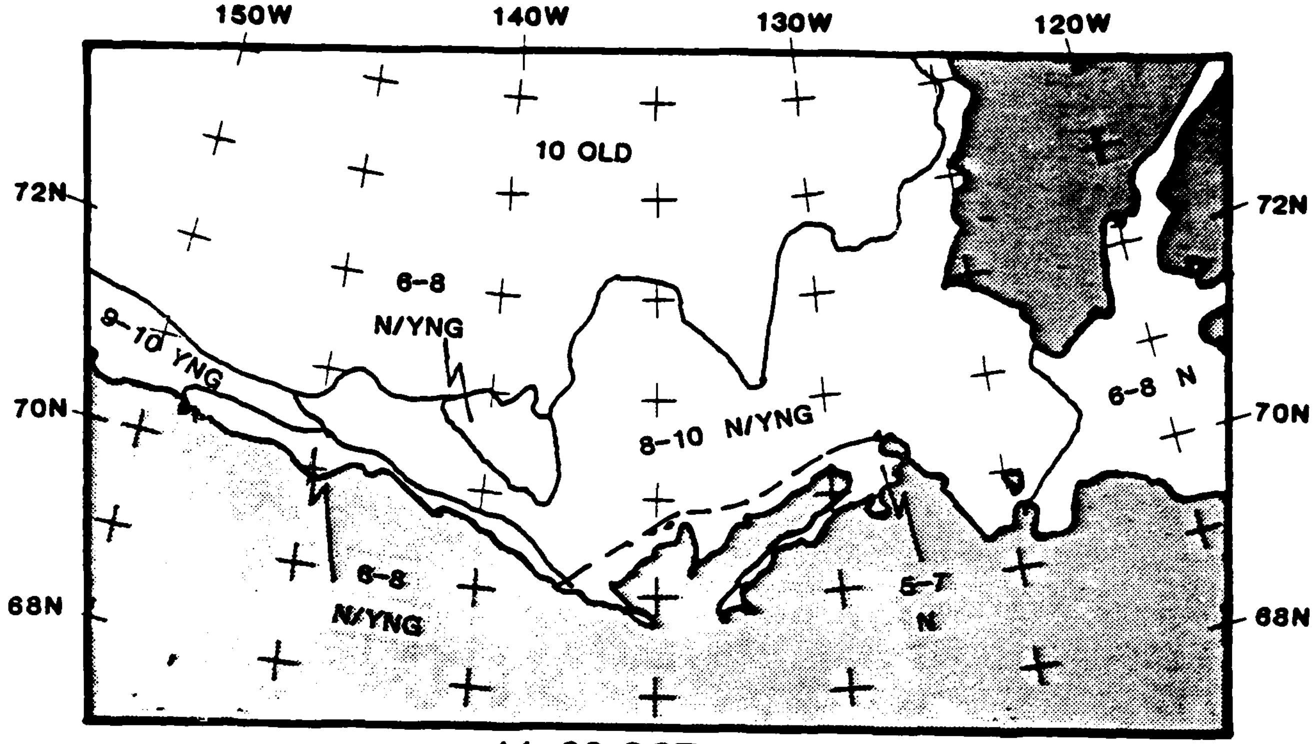
8. 7 OCT 1980



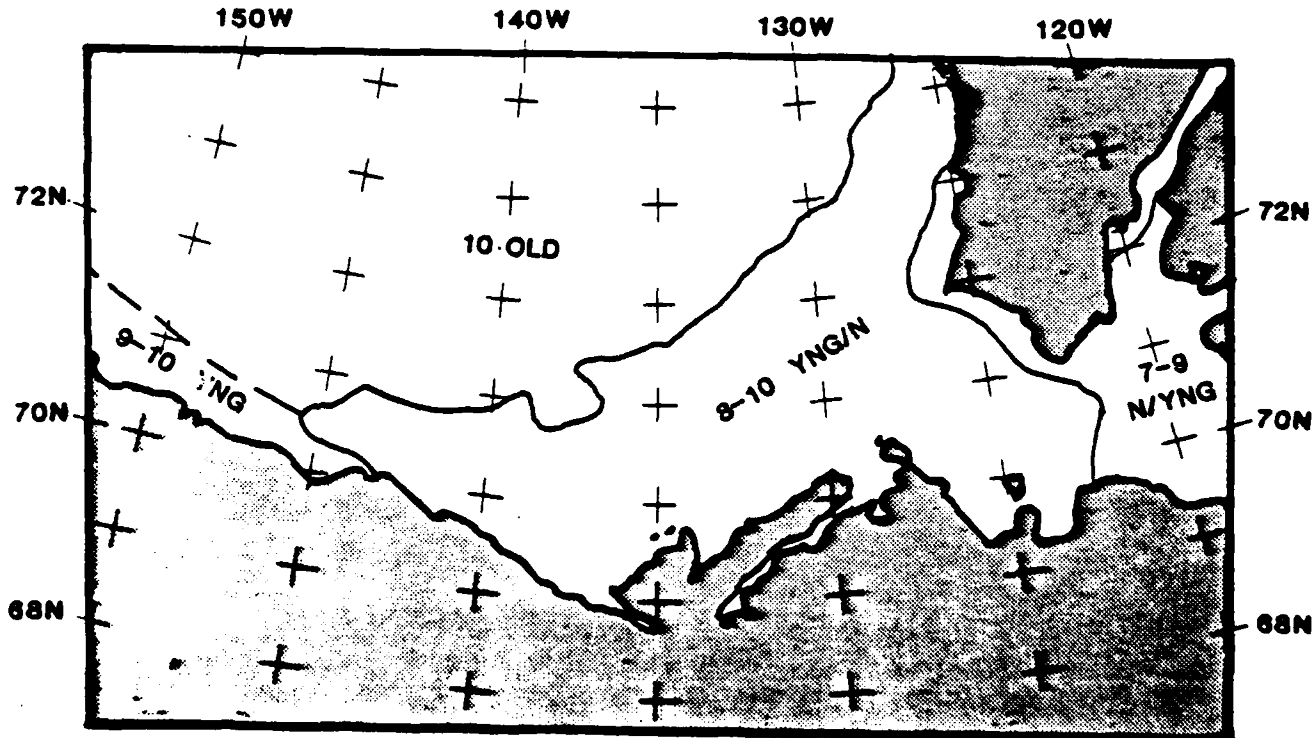
9. 16 OCT 1980



10. 21 OCT 1980



11. 28 OCT 1980

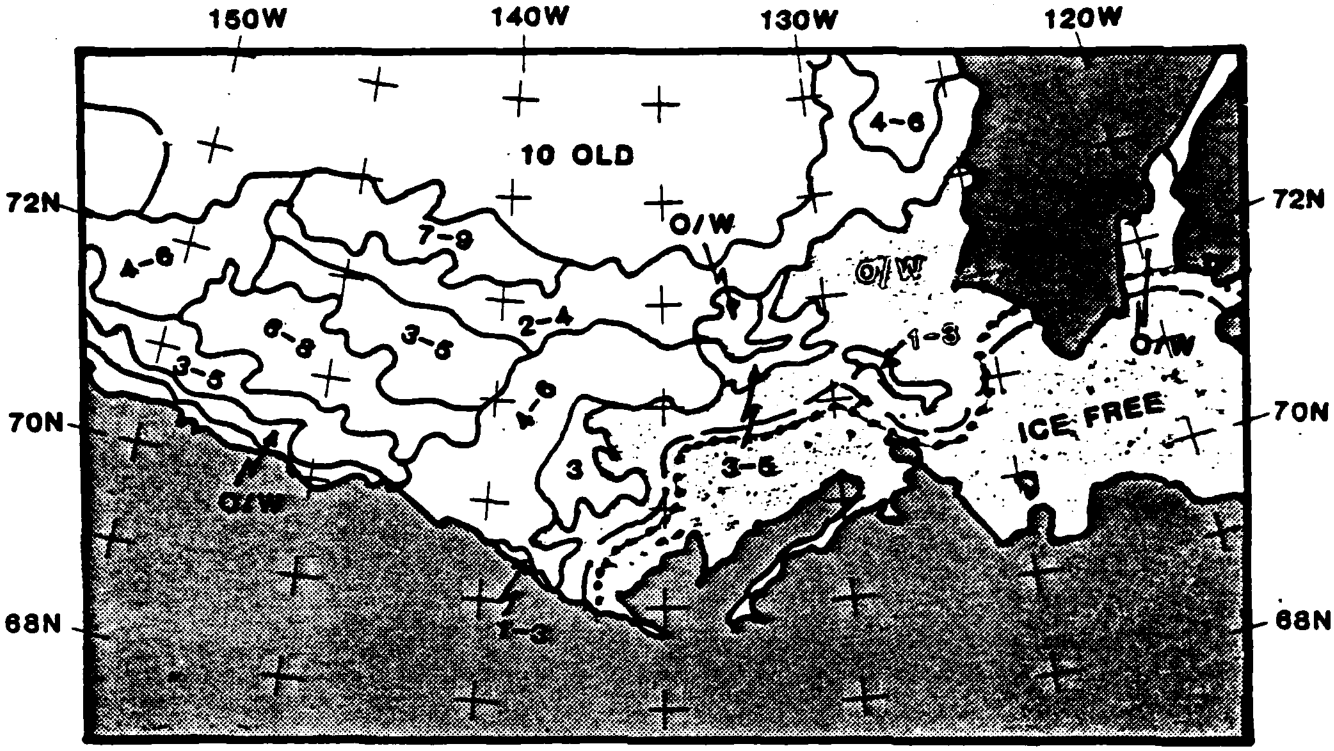


12. 4 NOV 1980

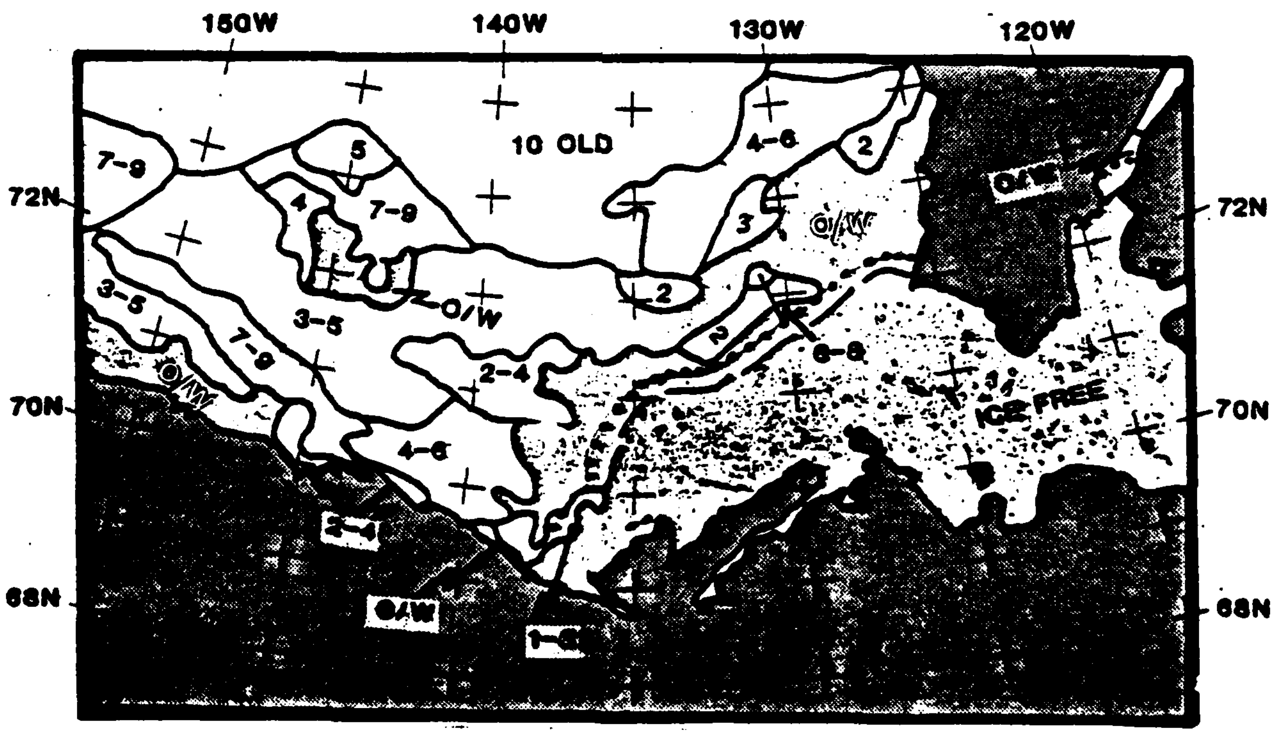
APPENDIX B

1981 Sea Ice Concentrations

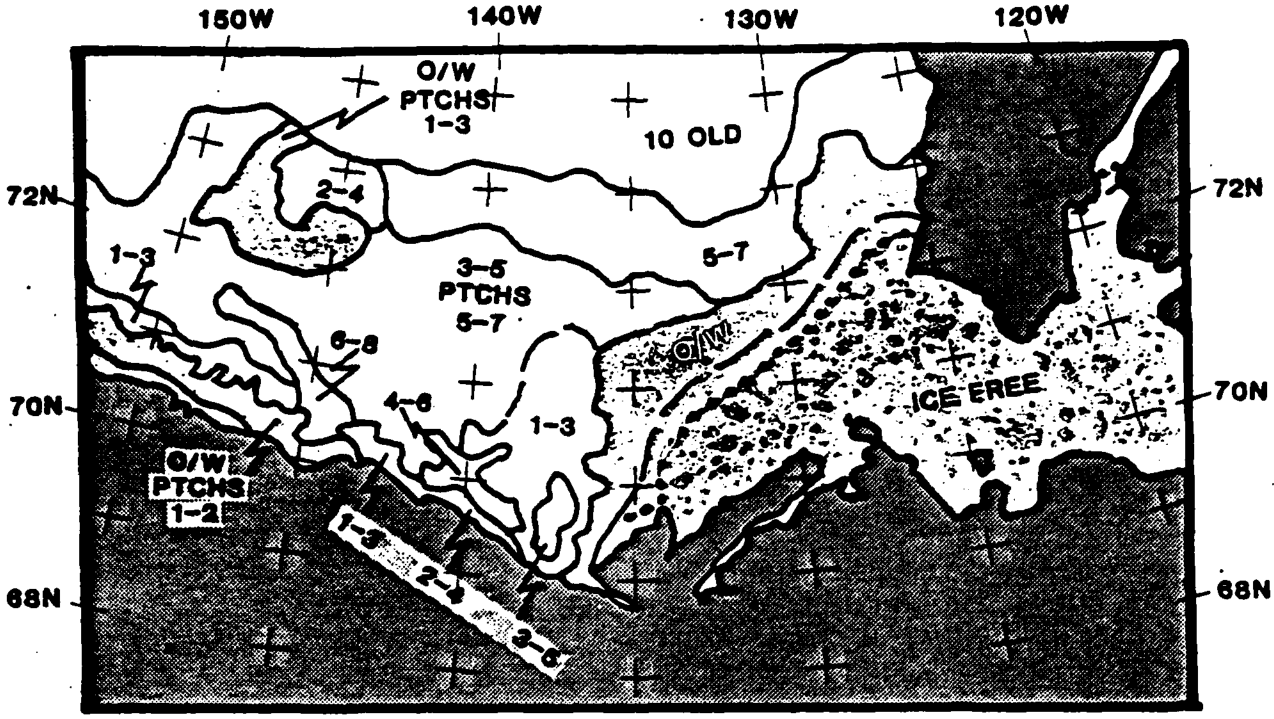
Weekly sea ice concentrations in the study area for the period 11 August - 17 November 1981.



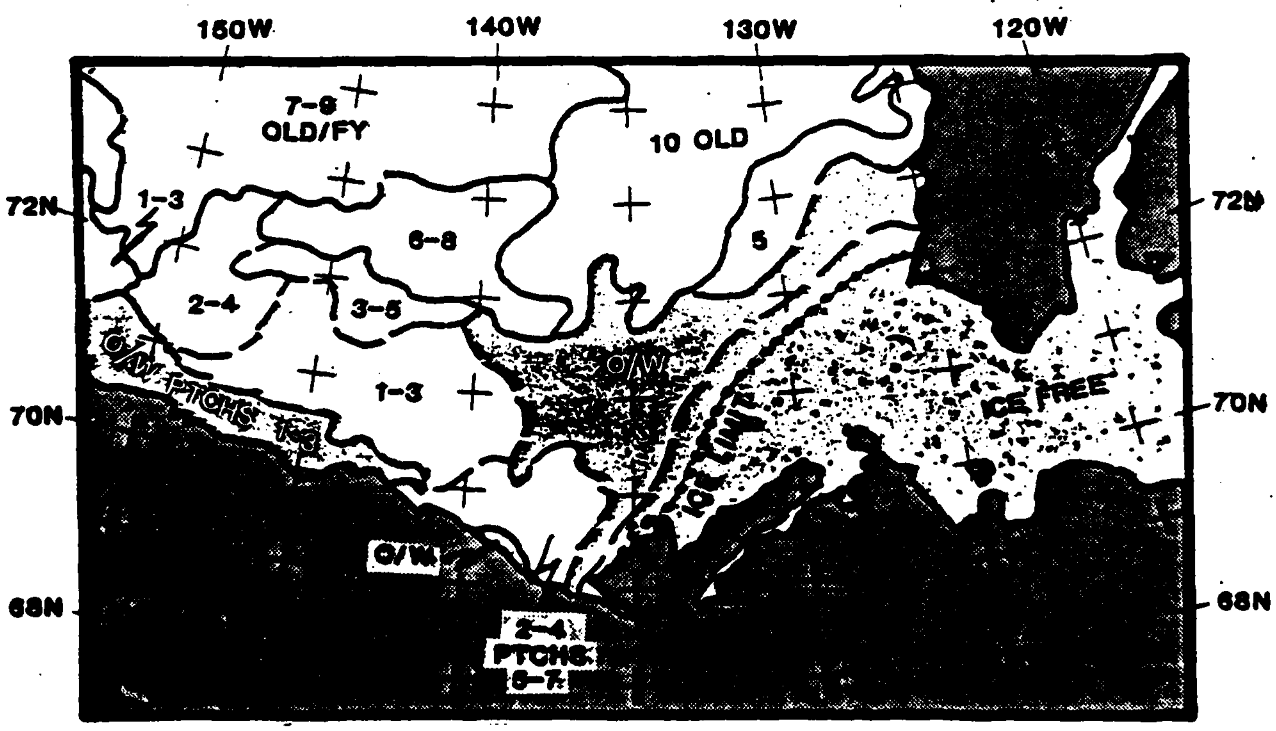
1. 11 AUG 1981



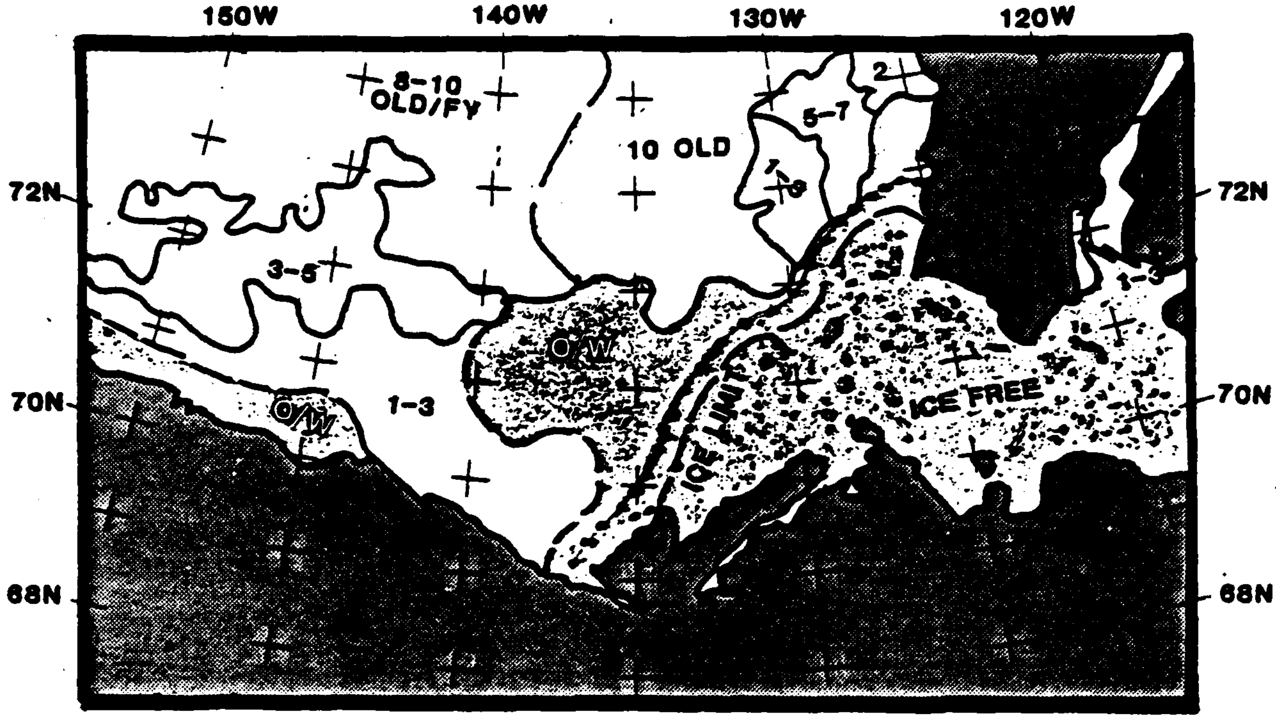
2. 18 AUG 1981



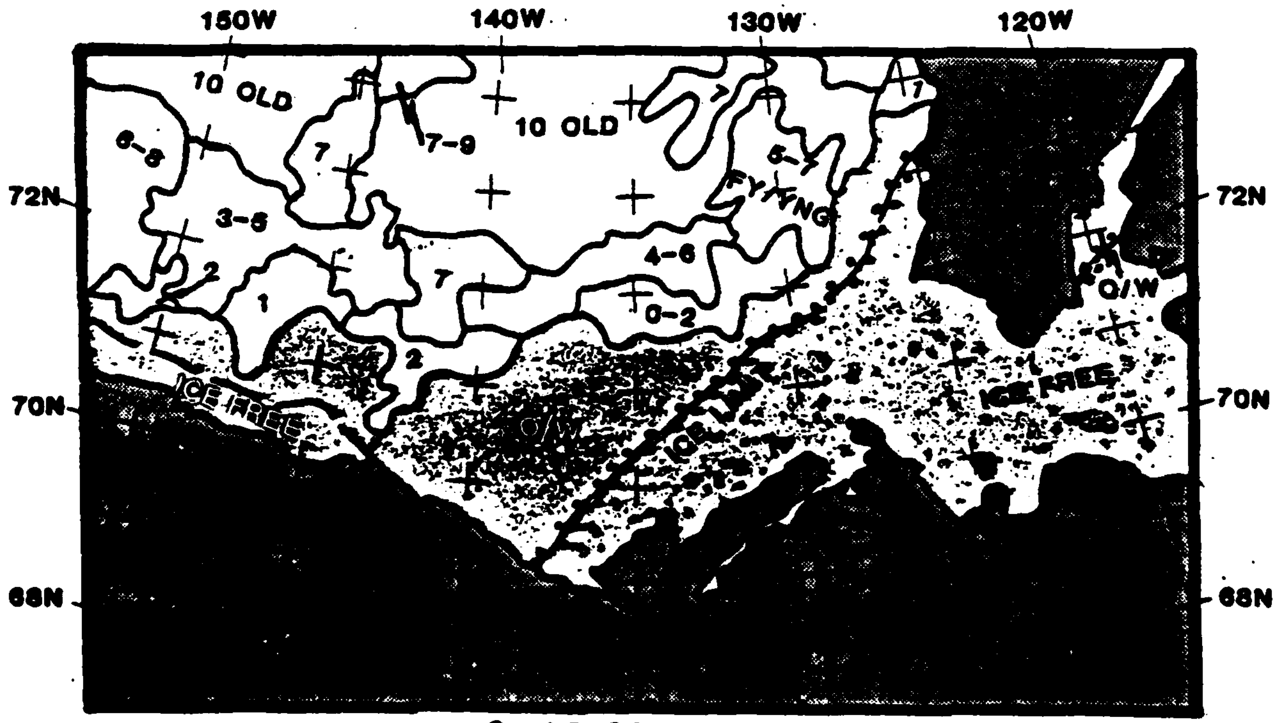
3. 25 AUG 1981



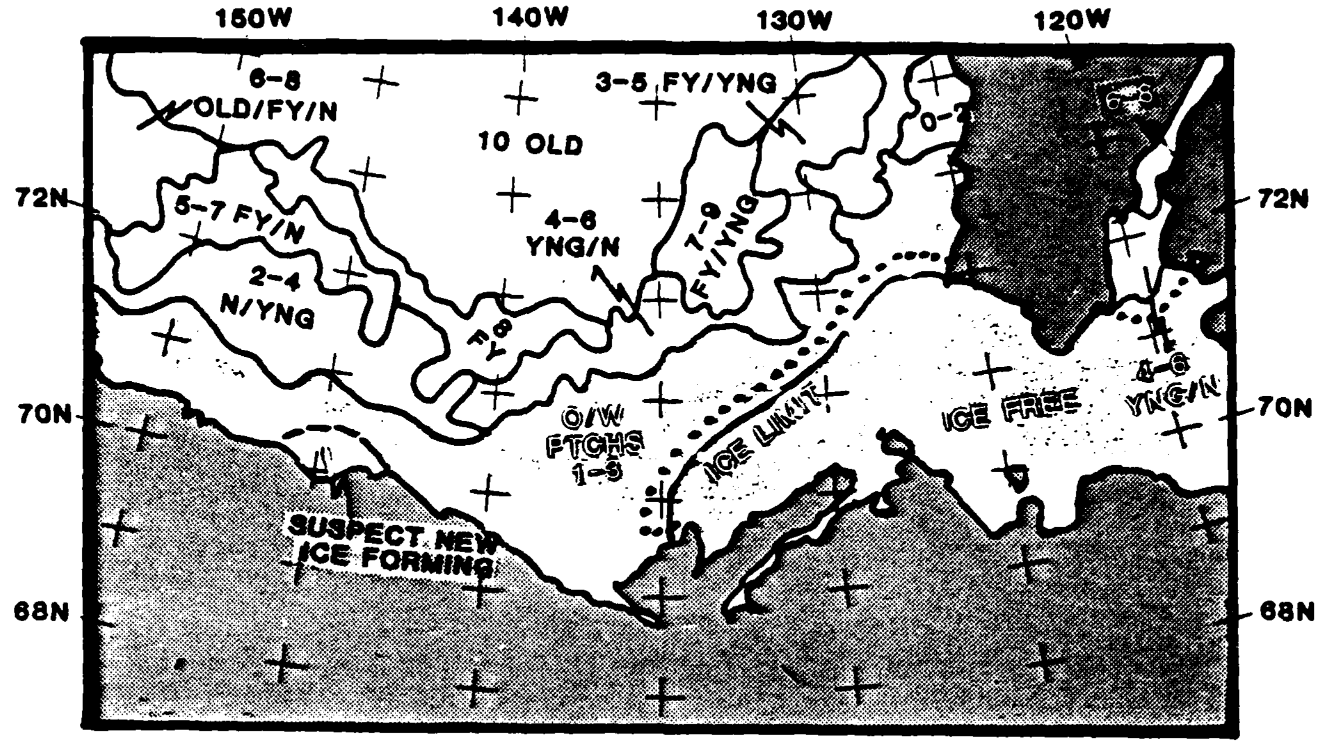
4. 1 SEP 1981



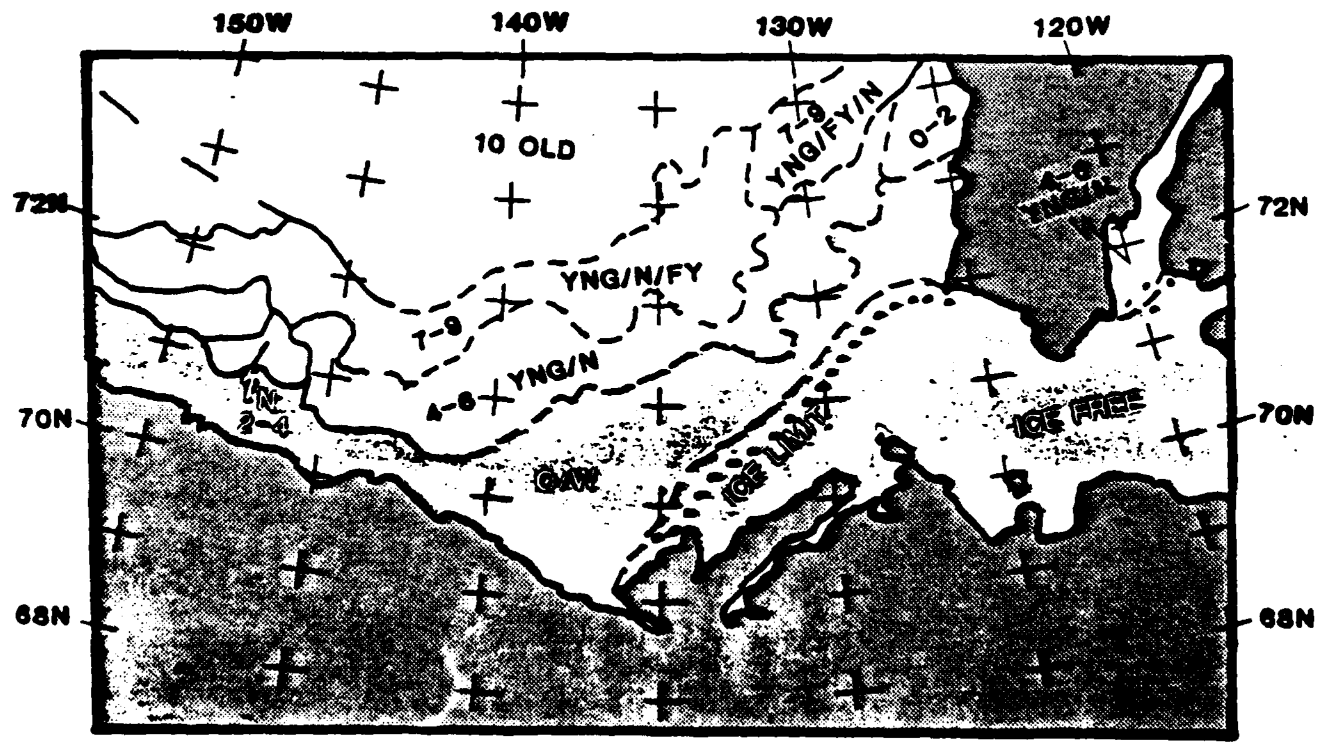
5. 8 SEP 1981



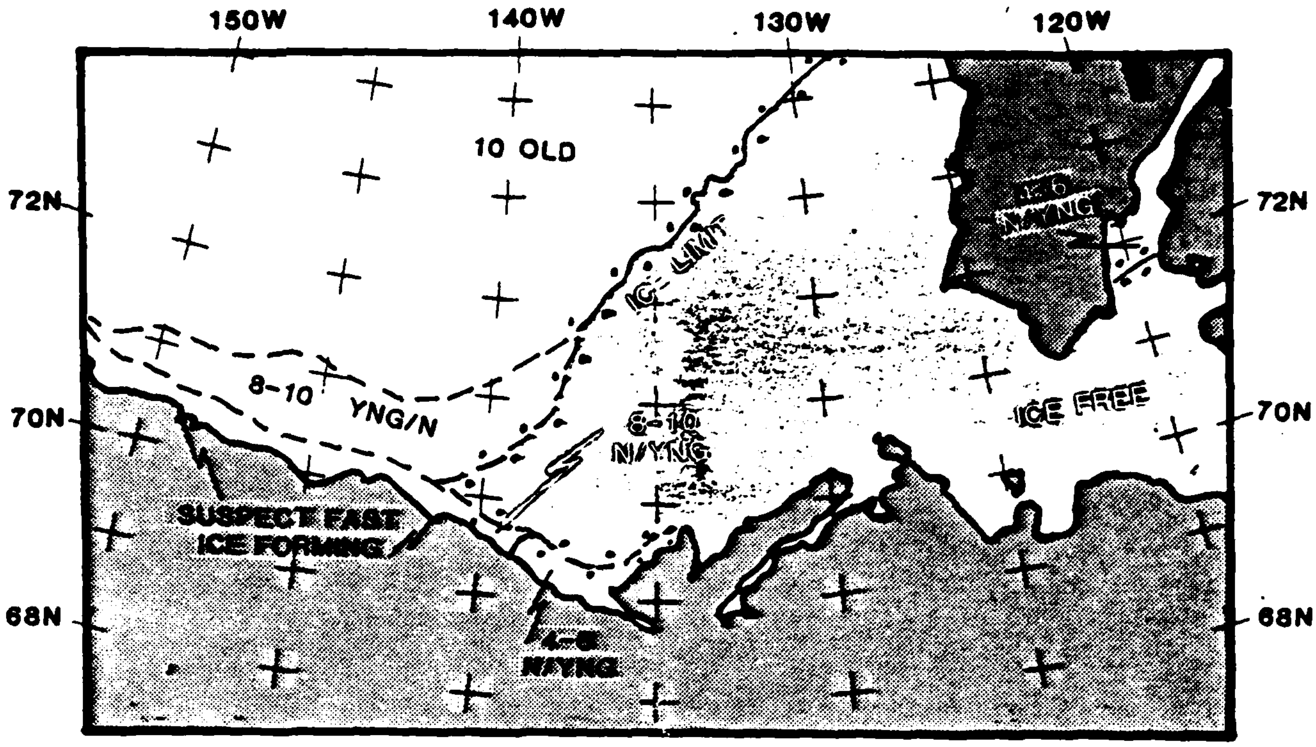
6. 15 SEP 1981



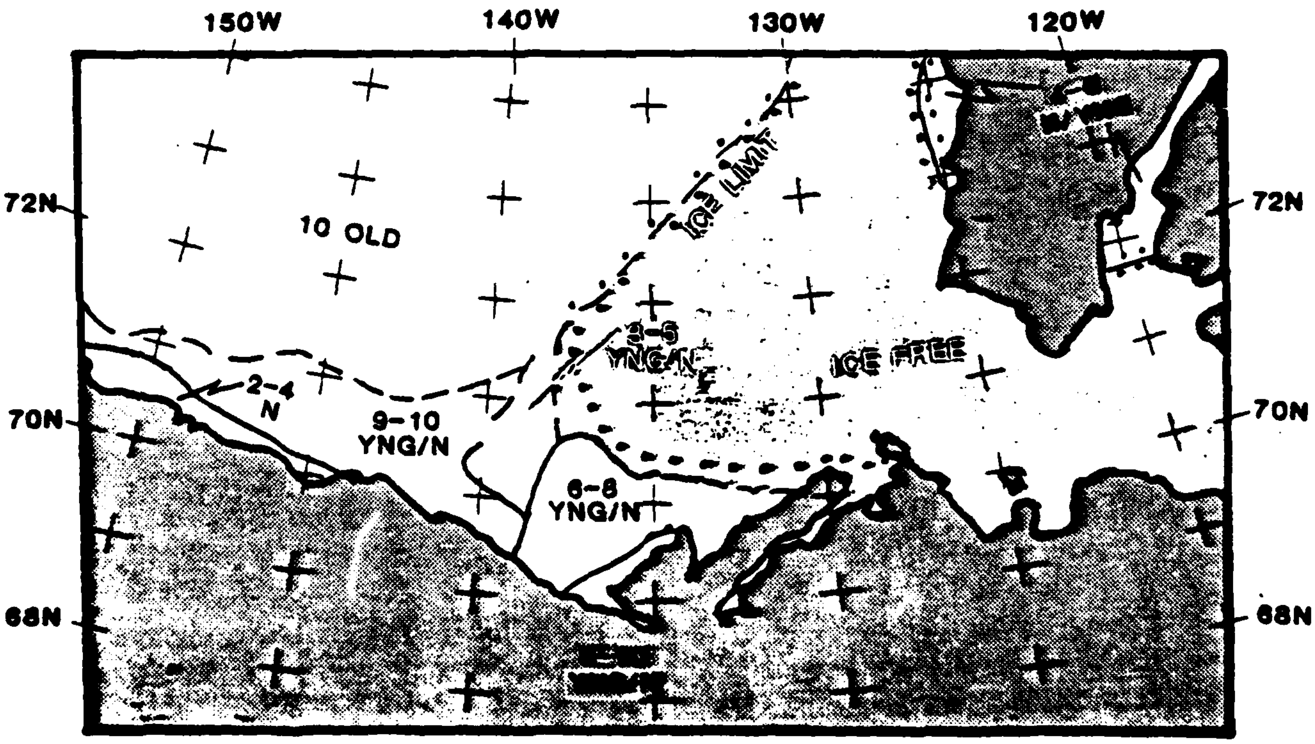
7. 22 SEP 1981



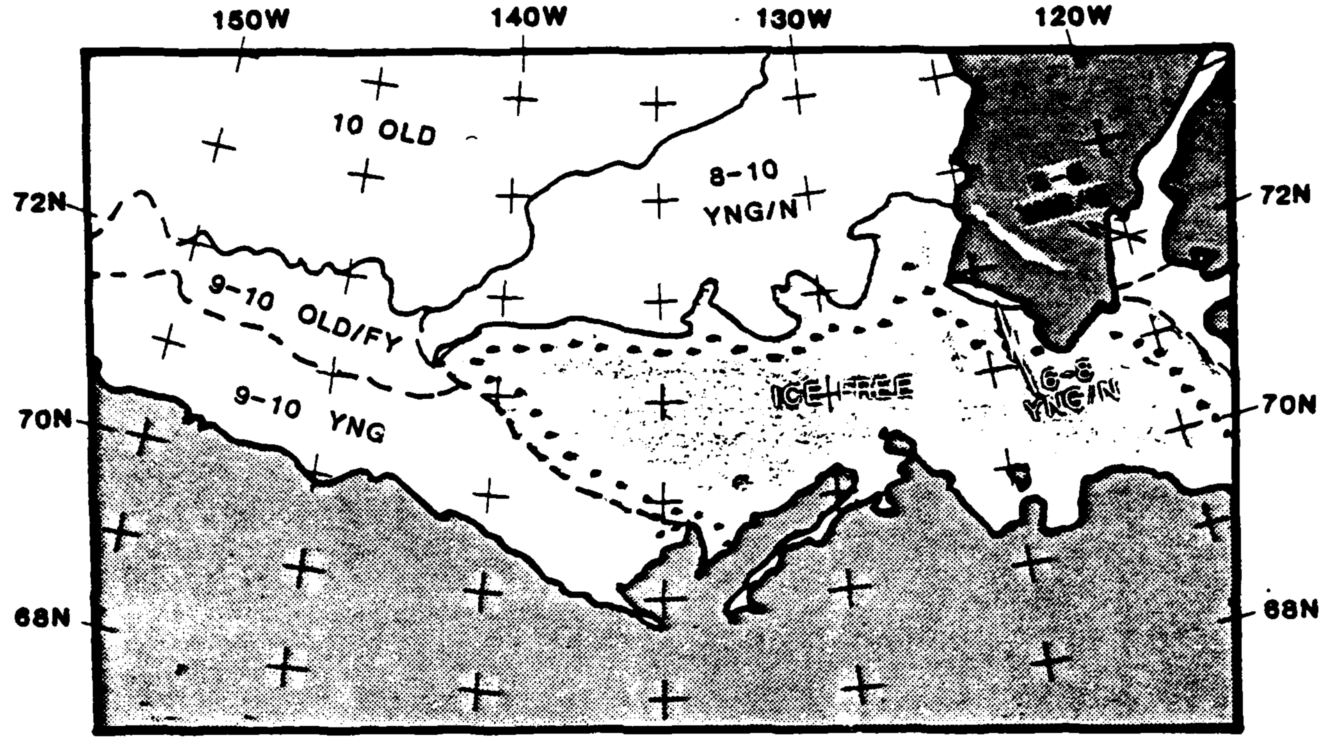
8. 29 SEP 1981



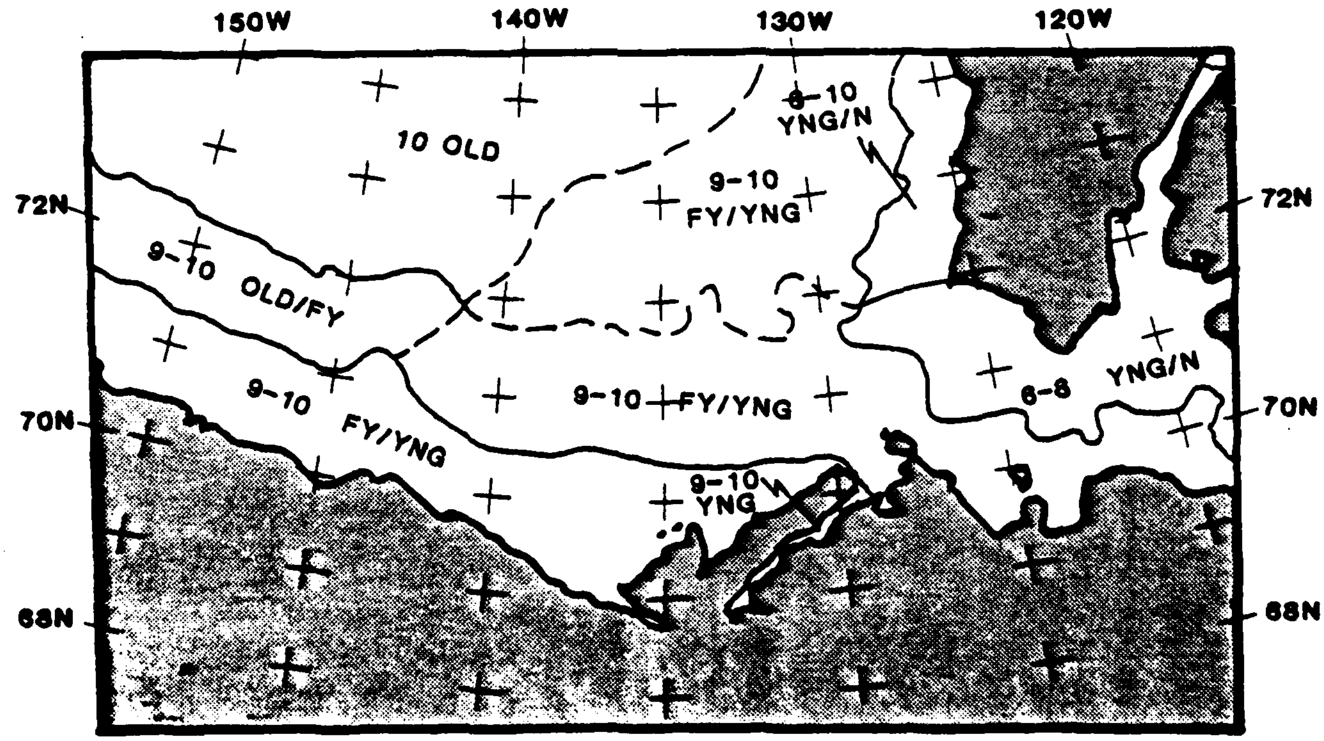
9. 6 OCT 1981



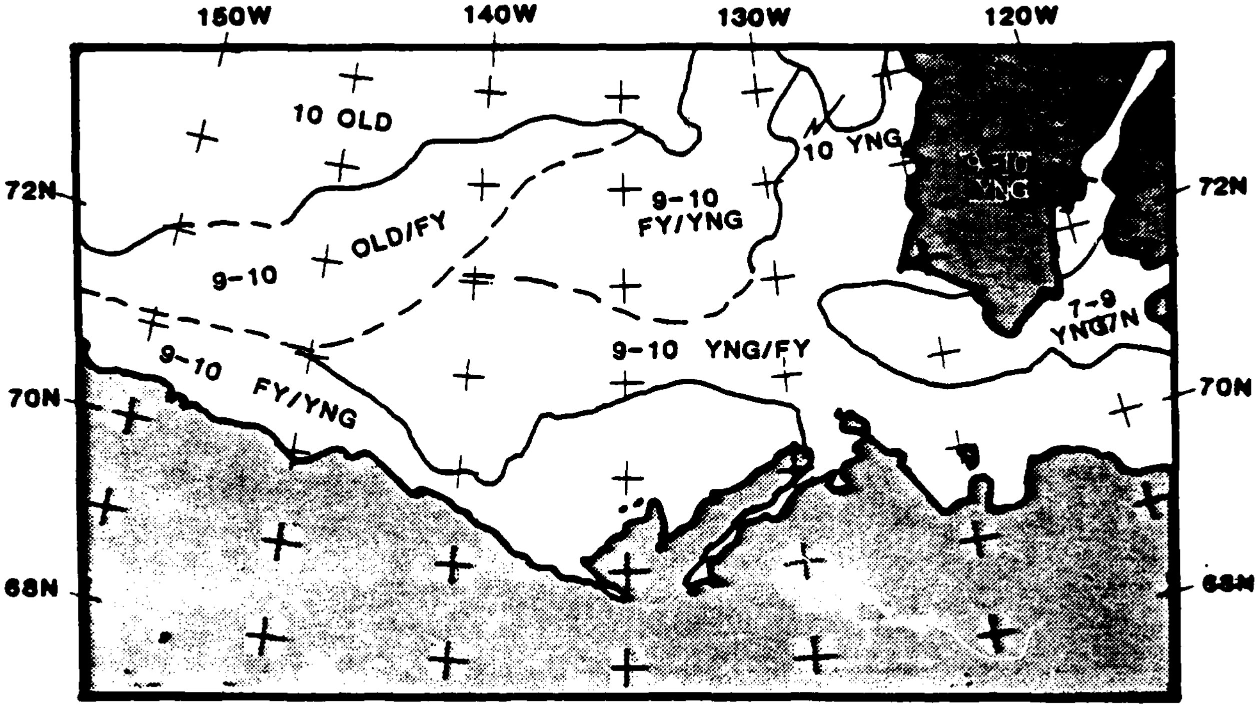
10. 13 OCT 1981



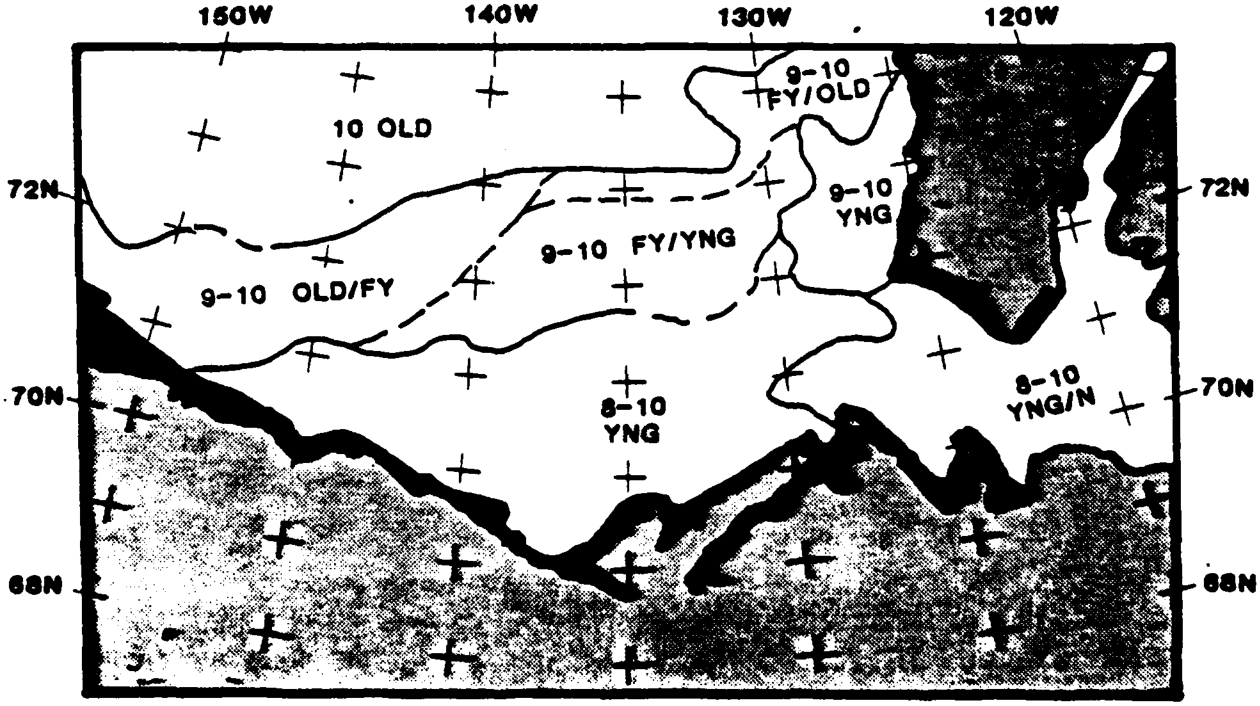
11. 20 OCT 1981



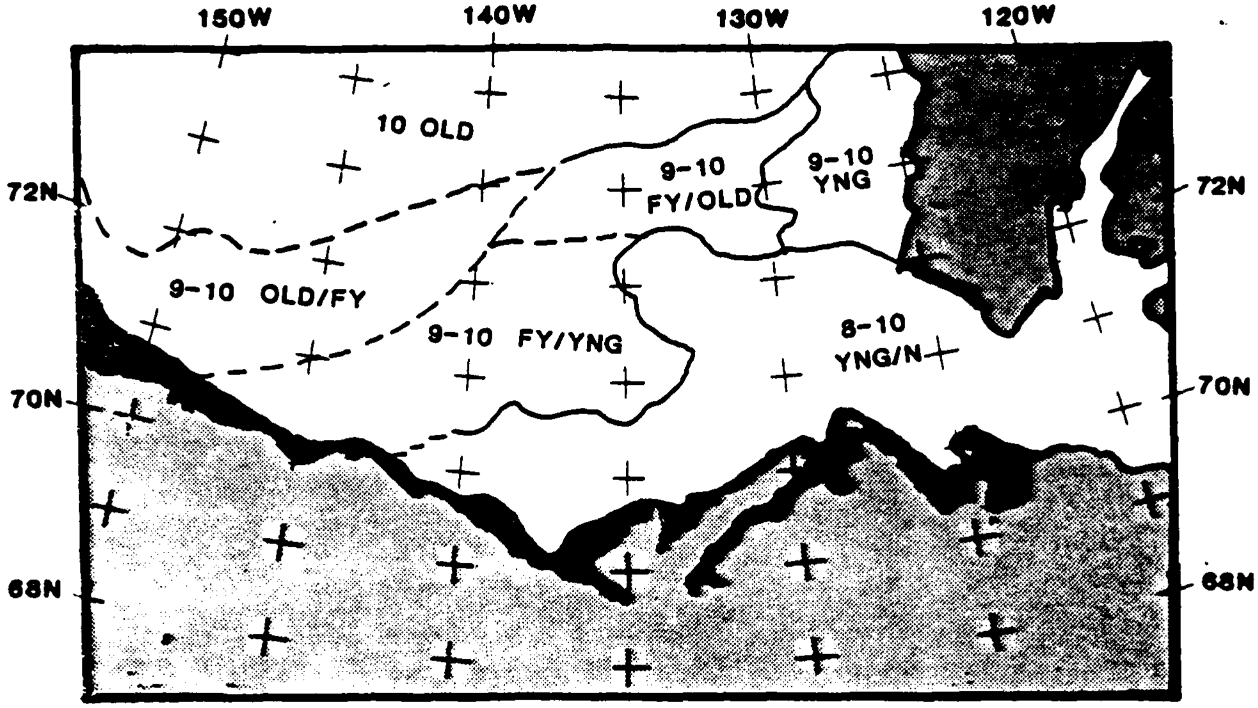
12. 27 OCT 1981



13. 3 NOV 1981



14. 10 NOV 1981



15. 17 NOV 1981

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